Future low temperature district heating design guidebook

Final Report of IEA DHC Annex TS1. Low Temperature District Heating for Future Energy Systems

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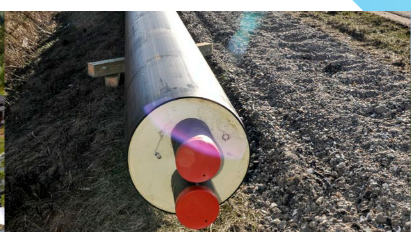

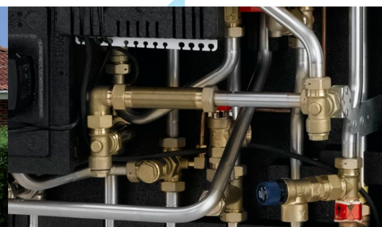

FINAL REPORT

FUTURE LOW TEMPERATURE DISTRICT HEATING DESIGN GUIDEBOOK

Edited by Dietrich Schmidt and Anna Kallert

International Energy Agency
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District Heating and Cooling including Combined Heat and Power

IEA DHC|CHP

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Low Temperature District Heating for Future Energy Systems

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Further information about the IEA DHC programme may be obtained from

www.iea-dhc.org

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EXECUTIVE SUMMARY

The building sector is responsible for more than one third of the end energy consumption of societies in industrialized countries and produces the largest amount of greenhouse gas emissions (GHG) of all sectors. District heating can contribute significantly to a more efficient use of energy resources as well as better integration of renewable energy into the heating sector (e.g. geothermal heat, solar heat, heat from biomass combustion or waste incineration), and surplus heat (e.g. industrial waste heat). The more efficient use of all energy resources and the use of renewable energy are measures which lead to a reduced utilization of fossil energy, and thereby a reduction of GHG emissions to fulfill the set climate goals. Low temperature district heating is a heat supply technology for efficient, environmental friendly and cost effective community supply. In comparison to conventional district heating, the network supply temperature is reduced down to approximately 50 °C or even less. Within this context, low temperature district heating offers prospects for both the demand side (community building structure) and the generation side (properties of the networks as well as energy sources). Especially in connection with buildings that require only low supply temperatures for space heating, low temperature district heating offers new possibilities for greater energy efficiency and utilization of renewable energy sources, which lead to reduced consumption of fossil fuel based energy.

The IEA DHC Annex TS1 is a three year international research project which aims to identify holistic and innovative approaches to communal low temperature heat supply by using district heating. It is a framework that promotes the discussion of future but also existing heating networks with an international group of experts. The goal is to obtain a common development direction for the wide application of low temperature district heating systems in the near future.

As part of the project promising technologies for low temperature district heating application have been collected and identified to meet the goals of future renewable based community energy systems. Background materials and cutting edge knowledge on district heating pipe systems, network designs, hygienic domestic hot water preparation in low temperature supply schemes, space heating controls and the integration of small scale decentralized heat sources is provided in the report for designers as well as decision makers in the building and district energy sector.

The analysis of the future heat demand showed that the district heating would still be needed for most of the buildings in 2050, inducing that the low temperature district heating is a promising heat supply for the future and for many buildings. Considering that there is enough available heat from renewables and waste heat sources at the low temperature level, the low temperature district heating will be of high relevance in the future. For future development of the district heating and a high reliability of the low temperature district heating, statistical data and knowledge on the heat losses and how operation or temperature levels may contribute to the distribution losses are highly necessary.

For the identification of integral and innovative approaches to low temperature heat supply at municipal level, an overview of a number of existing evaluation methods is provided. The planning tools are assessed in seven categories: analytical approach, target group of users, level of detail, model type, demand categories, final energy consumption and used variables within the assessment. The evaluation of the collected tools has shown some promising approaches for low temperature district heating. However, none has been found to be fully appropriate for the objective of a simplified, holistic tool for the evaluation of low temperature district heating. By evaluating the selected planning tools for district heating schemes, requirements have been derived for the development of a simplified planning tool.

The so-called Easy District Analysis tool has been developed, based on the identified requirements for a simplified district heating planning tool. The intended target groups of the tool are urban planners and planners in utility companies. The tool is intended to be used in the pre-planning phase of a district energy system. The focus of the tool is on the evaluation of the impact of different grid temperatures and of different operation modes of district heating schemes. The assessment is based on the parameters primary energy consumption, carbon emissions and heat production costs.

In the description of different case studies innovative demonstration concepts as examples of success stories for communities interested in developing low temperature district heating systems are displayed. Demonstrated cases include the use of advanced technologies and the interaction between different components within the systems. Based on these experiences, principles and lessons learned in designing these systems are given. Measurement data from community projects are also used in validation of the models and tools developed. There were a total of eight case studies from Germany, Denmark, Finland, Norway and Great Britain. The district heating systems were of very different sizes, from smaller building groups to city wide systems. Taking into account the size of the supply area, the network lengths vary from 165 m to 140,000 m. The connected buildings were residential buildings of different sizes, and mostly low energy or passive houses. Sources of heat were solar collectors, heat pumps, combined-heat-and-power-plants, excess heat from industry or the systems were connected to a larger network close by with heat exchangers. The temperature levels recorded were typical for low-temperature systems, varying from 40 to 60 °C in supply and 25 to 40 °C in return. Savings and increased efficiencies were observed in every case studied.

The material collected and summarized in the presented guidebook show that low temperature district heating is a key enabling technology to increase the integration of renewable and waste energy for heating and cooling. More research and development work is needed to assess the practical and wider implementation of low temperature district heating schemes for various cases and locations. Especially ways to overcome the hindering reasons need to be identified. This supports more discussions to get low temperature heating systems built and in operation.

Low temperature district heating is one of the most cost efficient technology solutions to achieve 100 % renewable and GHG emission-free energy systems on a community level.

1 PREFACE

1.1 International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

1.2 Technology Collaboration Programme on District Heating & Cooling (DHC)

Established in 1983, the IEA Technology Collaboration Programme on District Heating & Cooling including Combined Heat and Power (IEA-DHC) brings countries together to research, innovate and grow district heating and cooling including CHP.

The IEA-DHC research programme addresses technical as well as policy issues aimed at low environmental impact. We select, manage and publish collaborative co-funded projects, collating and exchanging information on R&D projects between participating countries.

IEA-DHC programme control is vested in its Executive Committee, which comprises on official representatives from each participating country. The Executive committee maintains close links with Euroheat & Power and the International District Energy Association.

The Executive Committee closely cooperates with other IEA programmes. In particular the IEA-DHC is a member of the IEA's Building Coordination Group, resulting in more knowledge sharing and planning of joint activities.

The world may be challenged by climate change, but countries can make district heating and cooling including CHP part of an integrated energy and environmental solution.

The IEA's Technology Collaboration Programme on District Heating & Cooling has played a significant role in the DHC/CHP industry's history and will play a vital role in its even brighter future!

More information can be found at:

www.iea-dhc.org

To date, the following projects have been initiated by the IEA DHC Executive Committee (completed projects are identified by (*)):

1983-1987 / Annex I (*)
1987-1990 / Annex II (*)
1990-1993 / Annex III (*)
1993-1996 / Annex IV (*)
1996-1999 / Annex V (*)
1999-2002 / Annex VI (*)
2002-2005 / Annex VII (*)
2005-2008 / Annex VIII (*)

- New materials and constructions for improving the quality and lifetime of district heating pipes including joints - thermal, mechanical and environmental performance
- Improved cogeneration and heat utilisation in DH networks
- District heating distribution in areas with low heat demand density
- Assessing the Actual Annual Energy Efficiency of Building-Scale Cooling Systems
- Assessing the Actual Annual Energy Efficiency of Building-Scale Cooling Systems
- Cost benefits and long term behaviour of a new all plastic piping system

2008-2011 / Annex IX (*)
- The Potential for Increased Primary Energy Efficiency and Reduced CO2 Emissions by DHC
- District Heating for Energy Efficient Building Areas
- Interaction Between District Energy and Future Buildings that have Storage and Intermittent Surplus Energy
- Distributed Solar Systems Interfaced to a District Heating System that has Seasonal Storage
- Policies and barriers for District Heating and Cooling outside EU countries

2011-2014 / Annex X (*)
- Improved maintenance strategies for district heating pipelines
- Economic and Design Optimization in Integrating Renewable Energy and Waste Heat with Disrict Energy Systems
- Towards Fourth Generation District Heating: Experiences with and Potential of Low Temperature District Heating
- Development of an Universal Calculation Model and Calculation Tool for Primary Energy Factors and CO2 Equivalents in District Heating and Cooling including CHP

2012-2016 / Annex TS1
- Low Temperature District heating for Future Energy Systems

2014-2017 / Annex XI
- Transformation roadmap from high to low temperature district heating system
- Plan4DE: Reducing greenhouse gas emissions and energy consumption by optimizing urban form for district energy
- Smart use as the missing link in district energy development: a user-centred approach to system operation and management
- Structured for success: Governance models and strategic decision making processes for deploying thermal grids

2017-2020 / Annex XII
- Effects of Loads on Asset Management of the 4th Generation District Heating Networks
- Methodology to evaluate and map the potential of waste heat from industry, service sector and sewage water by using internationally available open data
- Integrated Cost-effective Large-scale Thermal Energy Storage for Smart District Heating and Cooling
- Stepwise transition strategy and impact assessment for future district heating systems

1.3 The IEA DHC Annex TS1

DHC Annex TS1 was a three year international research project.
The IEA DHC Annex TS1 aims to identify holistic and innovative approaches to communal low temperature heat supply by using district heating. It is a framework that promotes the discussion of future but also existing heating networks with an international group of experts. The goal is to obtain a common development direction for the wide application of low temperature district heating systems in the near future. District cooling can also be integrated into the activities but is not the focus. The gathered research which is going to be collected within this Annex should contribute to establishing DH as a significant factor for the development of 100 % renewable energy based communal energy systems in practice. By connecting the demand side (community/building stock) and the generation side (different energy sources which are suitable to be fed in the DH grids), this technology provides benefits and challenges at various levels. The activities are strongly targeted at DH technologies and the economic boundary conditions of this field of technology.

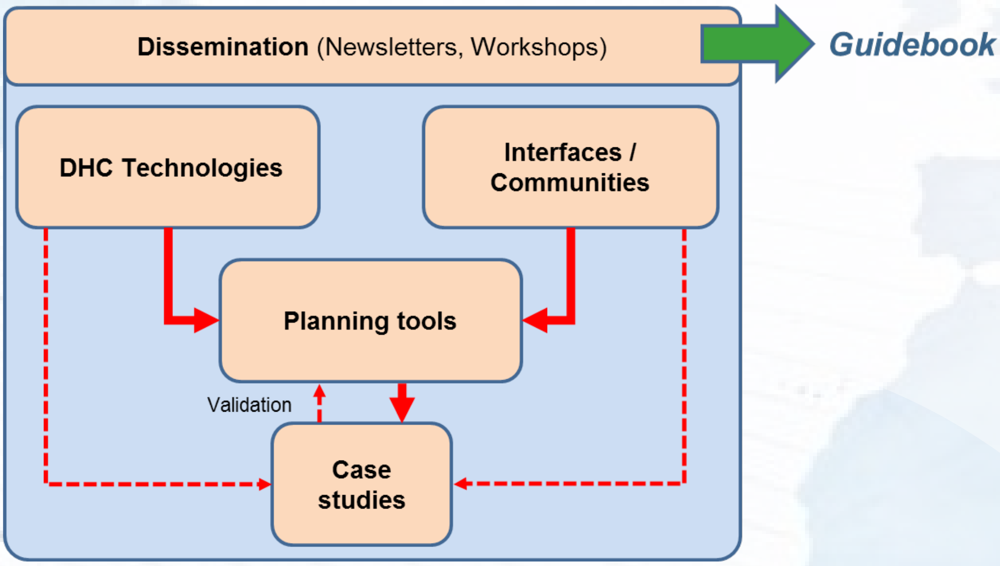

Figure 1-1 Structure of the IEA DHC Annex TS1

Further information about the project can be found on the internet under:

www.iea-dhc.org

1.4 Operating Agent:

This international cooperation project has been coordinated by the operating agent

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This Guidebook of DHC Annex TS1 is the result of a joint effort of many experts from various countries. We would like to gratefully acknowledge all those who have contributed to the project by taking part in the writing process and the numerous discussions. This cooperative research work is funded by various national sources and from industry partner. The authors would like to thank for the given financial support. A list of the participants within Annex TS1 and their corresponding countries can be found in the Appendix B. All participants from all countries involved have contributed to the guidebook. However, the following annex participants have taken over the responsibility of writing the chapters:

Dietrich Schmidt	Editor, operating agent and Subtask E coordinator, contributed to almost all chapters, especially chapters 1, 2, 3, 7 and 8
Anna Kallert	Editor, contributed to almost all chapters, especially chapters 4, 5, 6 and appendix A
Markus Blesl	Subtask A coordinator, especially chapter 6
Hongwei Li	Contributed to almost all chapters, especially chapters 3, 4, 6 and 7.2
Svend Svendsen	Subtask B coordinator, especially chapters 3, 4, 7.2 and 8
Natasa Nord	Subtask C coordinator, especially chapters 6 and 7.2
Kari Sipilä	Subtask D coordinator (2012-2015), especially chapter 7
Miika Rämä	Subtask D coordinator (2016), especially chapter 7
Oddgeir Gudmundson	Contributed to almost all chapters, especially 3, 4, 5 and 8
Maunu Kuosa	especially chapters 4.3 and 4.5
Michael Broydo	especially chapter 6
Markus Stehle	especially chapter 6
Ruben Pesch	especially chapter 7.2
Dirk Pietruschka	especially chapter 7.2
Heiko Huther	especially chapter 3 and 8
Andrej Jentsch	especially chapter 1, 2, 3 and 8
Tymofii Tereshchenko	especially chapter 6 and 7.2
Ciro Bevilacqua	especially chapter 7.2
Gunnar Lennermo	(guest) chapter 4.6

This report is a summary of the conducted work of DHC Annex TS1. The full and extended versions of the various detailed subtask reports are freely available on the internet (www.iea-dhc.org).

2 INTRODUCTION

2.1 Background and motivation

The building sector is responsible for more than one third of the end energy consumption of societies and produces the largest amount of greenhouse gas emissions (GHG) of all sectors. This is due to the utilization of combustion processes of mainly fossil fuels to satisfy the heating and cooling demand (the cooling demand is usually satisfied by use of electricity form combustion processes) of the building stock. District heating (DH) can contribute significantly to a more efficient use of energy resources as well as better integration of renewable energy into the heating sector (e.g. geothermal heat, solar heat, heat from biomass combustion or waste incineration), and surplus heat (e.g. industrial waste heat). The more efficient use of all energy resources and the use of renewable energy are measures which lead to a reduced utilization of fossil energy, and thereby a reduction of GHG emissions.
Within this context, it is mandatory to consider the entire energy chain to achieve a good overall system performance. This means evaluating all energy flows, from the extraction of primary energy, to the utilization of heat in buildings. This approach allows achieving optimal solution for supplying heat to the building stock, independently on the energy efficiency of single components of the system. The components of the DH System, such as the pipelines, the operational structures and the substations, are an integral part of the overall system optimization. For overall system optimization it is therefore necessary to take into account the building stock, the structure of the considered community, energy infrastructure and the heat generation facilities for the assessment.
The IEA DHC Annex TS1 aims to identify holistic and innovative approaches to communal low temperature heat supply. It is a framework that promotes the discussion of future heating networks with an international group of experts. The goal is to obtain a common development direction for the wide application of low temperature district heating systems in the near future. District cooling can also be integrated into the program but is not the focus. The gathered research which was collected within this Annex should contribute to establishing DH as a significant factor for the development of 100 % renewable energy based communal energy systems in international research communities and in practice. In connecting the demand side (community/building stock) and the generation side (different energy sources which are suitable to be fed in the DH grids), this technology provides benefits and challenges at various levels.

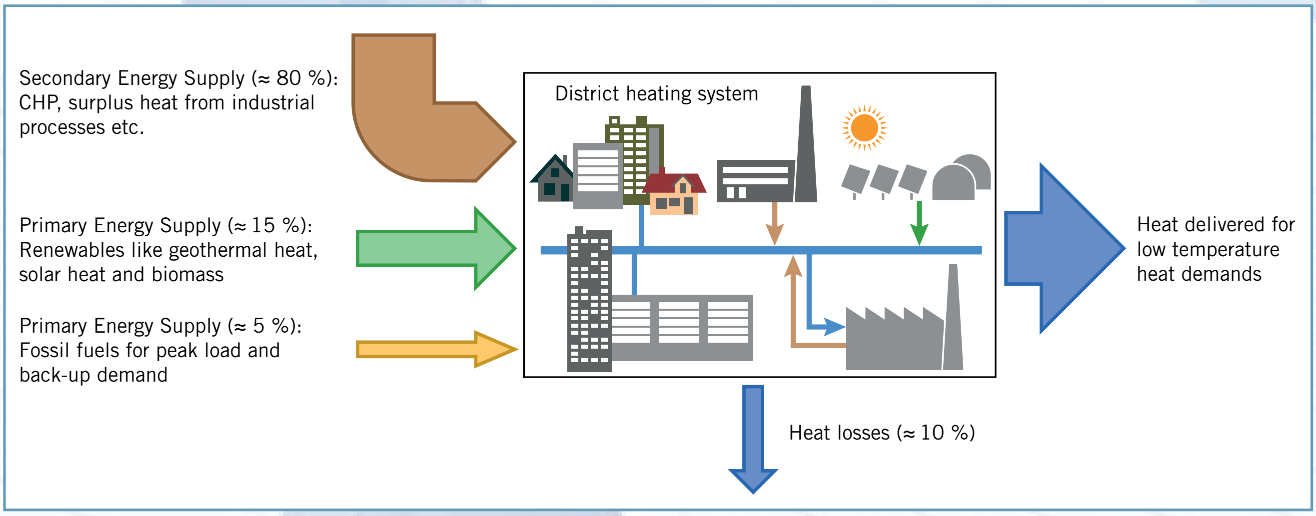

Figure 2-1 Example of a district heating system which incorporates inputs from fossil and renewable energy sources, and utilizes surplus heat sources (acc. Frederiksen and Werner, 2013)

2.2 Scope and objectives

The Annex TS1 is intended to provide solutions for both expanding and rebuilding existing networks and new DH networks. It is strongly targeted at DH technologies and the economic boundary conditions of this field of technology. The area of application under consideration is the usage of low temperature district heating technology on a community level. This requires a comprehensive view of all process steps: From heat generation over distribution to consumption within the built environment. The approach includes taking energy (e.g. primary energy, end energy, etc.) and exergy into account. This allows an overall optimization of energy and exergy performance of new district heating systems and the assessment of conversion measures (from high temperature DH to low temperature DH) for existing DH systems.

The main focus of DHC Annex TS1 is low temperature district heating for the application in space heating (SH) and domestic hot water (DHW) preparation. Since today it has been found that heating is by far more relevant for the building sector in areas where district energy is used, district cooling is not considered here (even so the future cooling demand is considered to be so big that the cooling market might actually surpass the DH market). This helps to keep the focus on the research initiative.

The main objective of the DHC Annex TS1 is to demonstrate and validate the potential of low temperature district heating as one of the most cost efficient technology solution to achieve 100 % renewable and GHG emission-free energy systems on a community level. This is reached by providing tools, guidelines, recommendations, best-practice examples and background material for designers and decision makers in the fields of building, energy production/supply and politics.

During the course of the Annex activities, the aim was to develop and improve means for increasing the overall energy and exergy efficiency of communities through the use of low temperature district heating. Therefore, the compilation of existing know-how for developing new district heating concepts and for implementing the results in existing grids is necessary. In this way, low temperature DH can become the least expensive way of realizing the future of fossil free energy systems in the heating sector. The new approach to DH is to support the setup of sustainable structures and safe energy systems for future building stock.

In order to achieve the described objectives challenges are identified. The development of appropriate solutions helps to reduce fossil energy consumption and, thus, emissions. The improvement areas are new methodologies, concepts, and technologies in the field of DH. This includes an improved integration of renewable and surplus heat as well as the adaption of energy and exergy demand by taking interactions of buildings and supply systems into account.

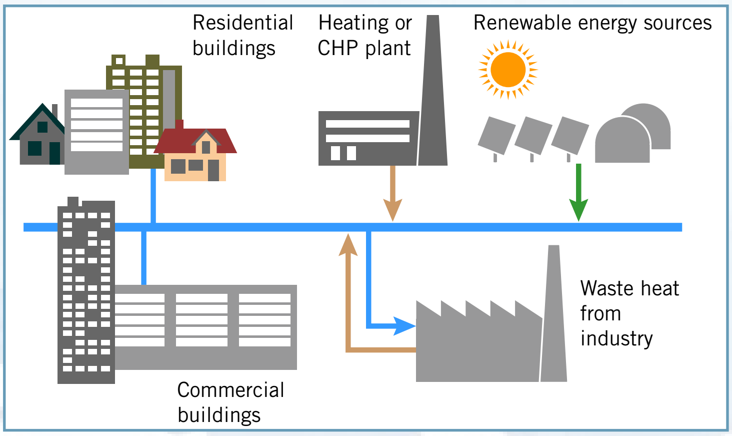

Figure 2-2 Schematic district heating community supply system with multiple supply options.

Additionally, economic aspects must be taken into consideration. In this context, new business cases and models could support the wider implementation of new and especially innovative low temperature DH systems. Next to this technology, developments for reduced DH network costs are necessary. It seems to be sensible to focus on the motivation for investments into new networks and the renovation of existing networks.

It can be said that the focus of Annex TS1 is based on the need of reducing resource consumption (including primary energy) and GHG emissions through overall system optimization in collecting the most recent knowledge in the DH sector in one place to maximize the future development rate.

2.3 Performance of low temperature district heating on a community scale

Low temperature district heating for future energy systems offers prospects for both the demand side (community building structure) and the generation side (properties of the networks as well as energy sources). Especially in connection with buildings that require only low supply temperatures for space heating, low temperature district heating offers new possibilities for greater energy efficiency and utilization of renewable energy sources, which lead to reduced consumption of fossil fuel based energy.

On the demand side, low temperature heat sources are commonly available and can serve as a basis for energy efficient space heating and domestic hot water (DHW) preparation. Even if the low temperature heat source has insufficient temperature level it can be integrated into the district heating system through temperature boosting, e.g. the use of efficient large scale heat pumps, solar thermal collectors or biomass fired - combined heat and power plants. Generally, the utilization of lower temperatures reduces transportation losses in pipelines and can increase the overall efficiency of the total energy chains used in district heating. To achieve maximum efficiencies, not only the district heating networks and energy conversion need to be optimal, but also the demand side must be designed for using the low temperature supplied by the network. For this reason, the implementation of solutions based on large shares of renewable energies may require an adaptation of the technical and building infrastructure. The indoor temperature requirements in most building types (residential and non-residential buildings) are generally low (below 23 °C). With the right heating installation this demand can be met with supply temperatures of between 35-40 °C. In the case of the provision of domestic hot water, supply temperatures in the range of 50 °C should principally be sufficient to avoid the risk of (legionella) bacterial growth. Both renewable and surplus energy sources, which can be harvested very efficiently at low temperature levels, can fulfil this energy demand. On the community scale, synergies are maximized when buildings and building supply systems are regarded as integrated components of an energy system. A number of issues need to be addressed in regard to matching the demand created by space heating and domestic hot water on the building side with the available energy from the supply side in order to develop advanced low temperature heating networks.

2.4 Main objective and layout of the report

This report is a summary of the results obtained during the course of the Annex TS1 work. It is oriented to the target groups of designers and decision makers in the building and district energy sector as well as key persons in the energy supply industry. The report is intended to bring them closer to the concept of low temperature district heating by giving an overview on the main features and benefits of this way of supplying heat to building stocks. Therefore, technical details of the concept as well as the used technologies are outlined and explained in a simplified and applied manner. In addition, the main features of several low temperature district heating schemes and case studies highlight the main benefits of this approach. More details can be found in the more extended subtask report or in the material listed in Appendix C which is freely available under the homepage www.iea-dhc.org. This material is partly oriented to scientists and researchers working in the field of innovative district energy systems.

In this context the main objective of the DHC Annex TS1 is to demonstrate and validate the potential of low temperature district heating as one of the most cost efficient technology solution to achieve 100 % renewable and GHG emission-free energy systems on a community level, as already stated in detail in chapter 2.2. So, the topics mentioned above are treated in the following chapters: After a presentation of the general framework of the Annex TS1 activity within the International Energy Agency (IEA) in chapter 1 and an introduction into this report in chapter 2, chapter 3 gives a brief overview of the general concept of low temperature district heating. Several technical features as well as key benefits are highlighted there. In chapter 4 needed key technology sets are presented. District heating technologies as piping systems or thermal grid design layout are presented as well as an introduction in advanced secondary side / building technology is given. Various designs of substations, the connection to low temperature space heating systems and ways to prepare domestic hot water hygienically with a connection to a low temperature district heating scheme are explained. Chapter 5 highlights and summaries important topics for a realization of district heating schemes as the estimation of distribution losses or the development of heat demand structures. Furthermore, the issue of pricing and business models is covered. In chapter 6 an analysis of various tools and software models for the planning and design of district heating systems is presented. The tools are briefly described and their properties are displayed. Built on this analysis the simplified Microsoft Excel based tool, the developed Easy District Analysis (EDA), is described. Chapter 7 gives an insight into seven real live case studies of the application of low temperature district heating to community heat supply from the participating countries.

3 LOW TEMPERATURE DISTRICT HEATING

3.1 What is low temperature district heating?

Low temperature district heating is a heat supply technology for efficient, environmental friendly and cost effective community supply. Traditionally district heating grids are operated at temperature levels up to 100 °C (e.g. so-called 3rd Generation DH). In comparison with conventional district heating, in low temperature district heating the network supply temperature is reduced down to required temperature levels of about 50 °C or even less (4th Generation DH). Simultaneously low temperature district heating coupling with reduced network temperature and well-designed district heating network can reduce heat losses of the grid by up to 75 % comparing to the current system design. To achieve maximum efficiencies, the district heating network, energy conversion process and the end user installation within the supplied buildings need to be optimized to utilize lower network supply temperatures. When the building systems and district heating supply network are treated as one integrated system, synergies and economies of scale can be optimized on a community scale. Low temperature district heating is an enabling technology to increase the integration of renewable and waste energy sources for heating and cooling (e.g. from solar thermal collectors, biomass fired heating plants, combined heat and power systems or from (large) heat pumps to use excess electricity from wind power plants). This contributes to meet national and local GHG reduction targets.

3.2 A sustainable and flexible approach to the energy supply of communities

Low temperature district heating (LTDH) offers a sustainable and flexible approach to the energy supply of communities. On the buildings' side a number of issues of matching the demand need to be addressed to develop advanced low temperature heating networks. On community scale synergies are maximized, if buildings and building supply systems are regarded as integrated components of an energy supply solution. That is why implementation of solutions based on large shares of renewable energies requires an adaptation of technical and building infrastructure. In contrast to the current standard network design, the low temperature district heating concept goes further in optimizing the overall system. One of the key differences between the traditional approach and the low temperature district heating approach is that an energy quality match is performed between the end-user thermal comfort requirements and the energy supply options at the same time as the energy transportation infrastructure is designed. By going through the process the most efficient and economical way to satisfy the heat demand is identified. Furthermore, by matching the energy quality of the supply to the demand the low temperature district heating opens up for further possibilities for achieving greenhouse gas (GHG) emission free supply systems based on waste heat and renewable energies only.

3.3 An economically efficient low temperature heating energy supply

Specifying low network temperatures opens up for a heat source flexible approach to the heating energy supply of communities and results in economically competitive solutions, because of the easy integration of different renewable or waste heating energy sources into the supply systems. From an economical point of view, relatively high price stability can be expected due to the use of locally available, renewable, or surplus heat energy sources. An additional advantage of this is a lower dependency on fossil fuel supplies, which leads to increased energy supply security. The high overall system performance can be achieved by using innovative low temperature district heating technologies which leads to reduced resource consumption as well as higher fuel efficiencies and lower total costs for fuels. For this reason, low temperature district heating is seen as an emerging innovative system technology with high potential to replace current technologies.

4 DISTRICT HEATING AND COOLING TECHNOLOGIES

4.1 Introduction

Since the first commercial district heating (DH) system was introduced in 1877 in Lockport, New York, the evolution of DH has gone through three generations which are characterized by the type of transport media, applied equipment and the network temperature levels. The 1st generation DH system is steam-based system which includes a large diameter steam supply pipe and a small diameter condensing pipe to return condensed water. The 2nd generation DH uses pressurized hot water as transporting media to supply temperature above 100 °C, pipes were insulated onsite and substations were built onsite. The 3rd generation DH was introduced in 1970s. It represents medium network supply temperature between 80 °C to 100 °C. The 3rd generation DH is the dominant DH technology in Nordic countries. The DH pipes in the 3rd generation network use pre-fabricated, pre-insulated metal pipes directly buried in the ground and substations became factory assembled and insulated (Frederiksen and Werner, 2013).

Today, the 4th generation DH (4GDH) is emerging as a new system to replace the existing 3rd generation DH system. 4GDH is also named as low-temperature DH (LTDH). The benefits are both in heat distribution and heat generation. In the heat distribution, it reduces the network heat loss, improves quality match between heat supply and heat demand and reduces thermal stress and risk of scalding. In the heat generation, lower network supply and return temperature helps improve CHP plant power to heat ratio and recover waste heat through flue gas condensation, achieves higher COP values (efficiencies) for heat pump, and enlarges the utilization of low-temperature waste heat and renewable energy. LTDH has been continuously developed as the next generation DH and is ready to replace the current medium temperature DH system.
LTDH based on renewable energy can substantially reduce total greenhouse gas emissions and secure energy supply for future development of society (Lund et.al 2014). It has the ability to supply low-temperature DH for space heating and domestic hot wa-

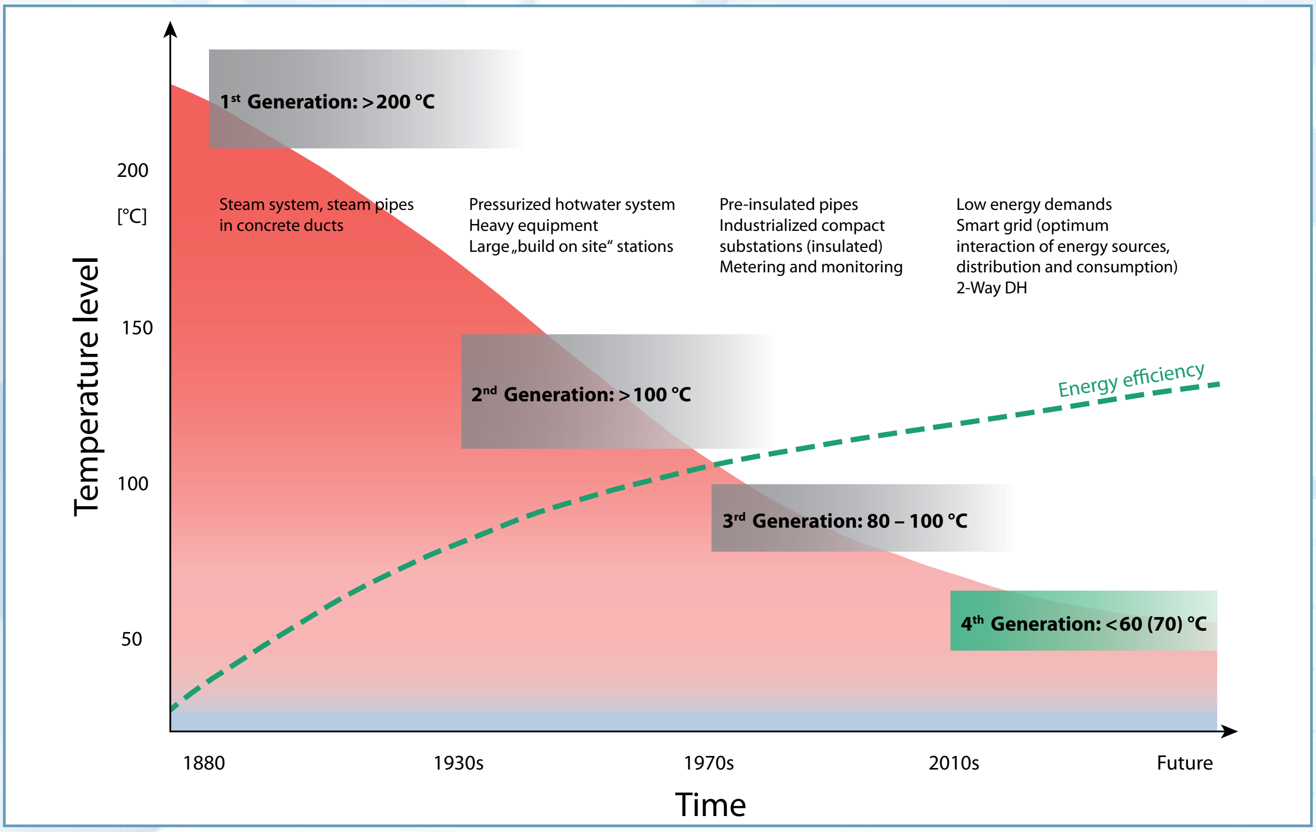

Figure 4-1 Development of the district heating technology © Fraunhofer IWES

ter (DHW) for various types of buildings, to distribute heat with low heat losses and ability to recycle heat from low-temperature waste heat and renewable energy sources. From various research and development of LTDH projects, it has been shown that it is both technically feasible and economically sound to change current high/medium temperature district heating system to LTDH for both new and existing building areas (Rosa et al. 2014).
During the course of the IEA DHC Annex TS1 project promising technologies and ideas for LTDH application have collected and identified to meet the goals of future renewable based community energy systems. Innovative technologies and advanced system concepts in LTDH are reported for heat generation, distribution and end user utilization. This special chapter aims to provide background materials and cutting edge knowledge for designers and decision makers in the building and district energy sector.

4.2 District Heating Pipes

The heat loss in a DH system occurs in different places in the heat generation, distribution and utilization, appearing in different forms. This section describes the heat loss in the district heating network. The success of LTDH largely relies on substantially reduced distribution heat loss. In this chapter different types of pipes and insulation materials applied in LTDH are described and a general steady state heat loss equation for co-insulated pipes is introduced.

4.2.1 Influence factors for network heat loss

The network heat losses account for a significant portion of annual operational cost and environmental impacts if the heat source is based on fossil fuel. The network heat loss is relevant in the following aspects:

- The annual district heating network heat loss influences the district heating economy.
- The network heat loss influences the required bypass flow rate through the thermostatic bypass valve.
- Pipe heat loss is important in the network dynamic performance.

DH network heat loss is determined by multiple factors: geometrical condition (network dimension, length and ground conditions/properties), DH pipes (type of pipes, insulation materials/conditions) and DH operation (heating load, temperature level, bypass operation and other factors such as leakages) (Li 2015).

4.2.2 Types of DH Pipes Types

There are different types of pipes used in DH. Some of them are in the commercial market like single pipe and twin pipe. The rest are developed for the purpose of conceptual investigation which can be ideal for some specific conditions like triple pipe and double pipe with different diameter of the supply/return pipe. The commercial product includes both rigid pipes and flexible pipes with small diameter.
To reduce network heat loss, small pipe diameters and high performance pipe insulation is recommended in the distribution network and service pipes. Figure 4-2 shows a service pipe specifically designed for LTDH projects (EFP 2007) as an example. It is an AluFlex pipe with 10mm inner pipe diameter. The service pipe in AluFlex is a sandwich construction which consists of an aluminum pipe coated in-between the outer PE layer and inner PEX layer.

Figure 4-2 AluFlex Service Pipe (EFP 2017) and (Logstor 2017)

4.2.3 Insulation Properties

Pipe insulation forms the most critical thermal resistance in the DH pipe heat transfer. The higher the insulation level the less the network distribution heat loss becomes, thus improve the DH economy. The heat

transfer in an insulation material includes heat conduction through pores wall, heat conduction due to insulation gas collision, and heat transfer between pores wall due to long wave radiation.
Traditionally insulation material like mineral wool ($\lambda \approx 0.033$-0.04 W/mK) was used for district heating pipe insulation, but after introduction of PUR insulation ($\lambda \approx 0.024$ W/mK) it has been phased out gradually. Super-insulation, with thermal conductivity (λ) below 0.02 W/mK is in the experimental stage and is expected to be proven valuable for DH (Berge and Johansson 2012). Solutions to improve insulation effect include applying diffusion barrier in DH pipes and apply asymmetrical insulation in twin pipe to reduce return pipe heat loss (Figure 4-3).

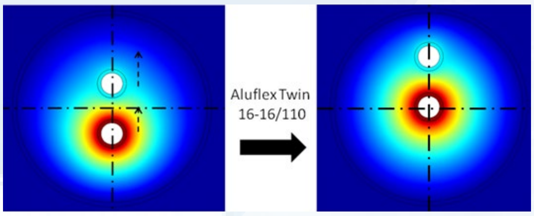

Figure 4-3 Asymmetrical twin pipe

4.3 Energy Efficient District Heating Network

4.3.1 Ring Network

In traditional DH network design, the pipe lengths between the heating plant and different consumers vary. The consumers close to the plant has larger available differential pressure, whereas the consumers away from the plant have smaller available differential pressure. In an uncontrolled pipe network, the pressure profile in the system would lead to more water flow through the consumers close to the plant and insufficient water flow through the consumers located far away from the plant. To overcome this, valves are installed in the network to increase the flow resistance until the required flow to fulfill consumer's heat demand is achieved.
One solution to reduce the valve throttling and potential hydraulic imbalance when the valves were malfunctioned is to apply a ring shape network topology. Unlike the traditional network, a topology based on ring network equalize the pressure differences between the supply and return pipes, which reduces the impact in case of malfunctioning valves (Kuosa et al. 2013).
Figure 4-4 (a) shows the traditional and ring network in an area of nine detached houses (1-9, DH) and two apartment buildings (1-2, AB) (Laajalehto et al. 2014). The idea of the ring topology is to have an equal pipe length for every consumer as presented in Figure 4-4 (b). The supply line (red line) begins from the heat station (HS) and ends with the last customer, as in the traditional network design. However, the return line (blue line) begins from the first customer and ends at the heat station. In both the supply and return lines, DH water circulates in the same direction. In ring networks twin pipes cannot be used, which might lead to higher heat losses. But double pipe with different pipe diameter might be used in these networks. On the contrary, in a traditional DH network design, the return line begins from the last customer and proceeds back to the heat station.

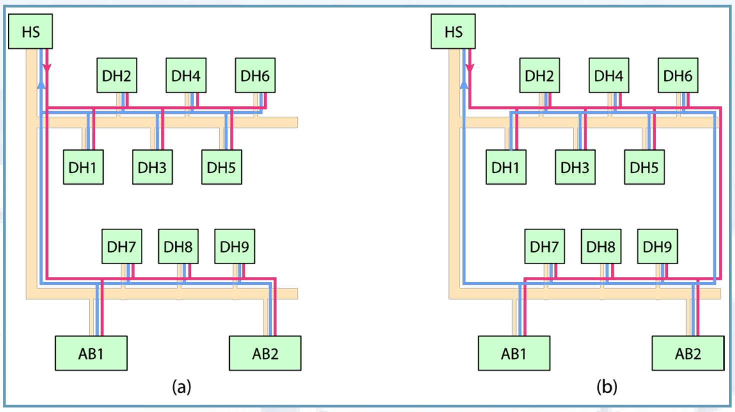

Figure 4-4 (a) Traditional district heating network design and (b) ring network design. The yellow lines are roads, the red line is the supply line, and the blue line is the return line. DH detached house, and AB apartment building (Laajalehto et al. 2014).

4.3.2 General solutions to avoid bypass flow in service pipes

When the network heating demand becomes low, the required mass flow rate is reduced accordingly. A smaller mass flow rate causes a larger water temperature drop along the pipeline due to heat loss to the ground. In non-heating season, the DHW load is low and its demand is intermittent with the total draw-off duration less than 1 h/day. To keep high thermal comfort, bypass valves are installed at the DHW subs-

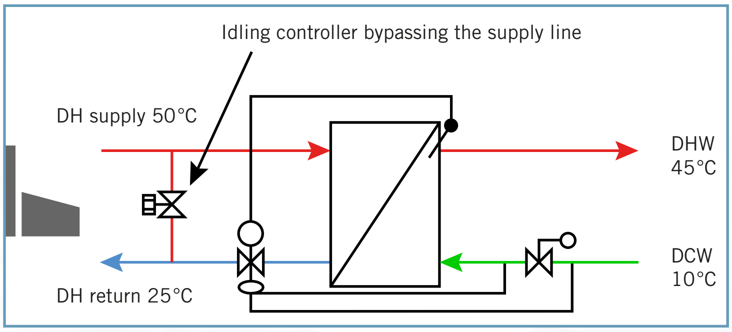

Figure 4-5 Bypass from supply pipe to return pipe © Danfoss

tation in order to keep the supply water temperature close to the set-point. The possible bypass functions include bypass from the supply pipe to the return pipe, bypass over the control valve or by applying set-back temperatures at the heat exchanger. Figure 4-5 shows the bypass from the supply pipe to the return pipe.

When there is no draw-off, the DH supply water is bypassed and flows back to the network return line without any cooling, it increases the network return temperature significantly and subsequently increases the network heat loss and decreases the thermal plant performance. This network performance degradation is particularly relevant for LTDH and DH supply to sparse areas.

To keep low network return temperature, it should be avoided to having the DH supply water directly mixed with the return water. Several solutions have been suggested to eliminate the service pipe bypass.

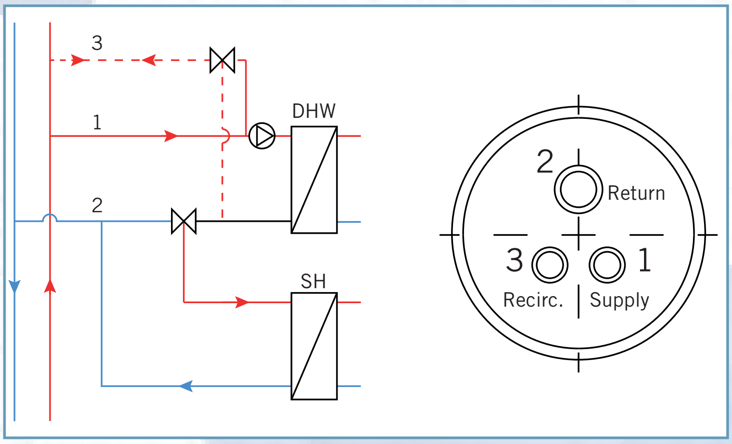

Figure 4-6 Minimum cooling concept with a triple service pipe (Dalla Rosa et al. 2011)

The 1st solution is based on the minimum cooling principle. A recirculation flow in the supply pipe warms up the service pipe and then flows back to the supply pipe in the street through a third recirculation pipe. The recirculation pipe can be a separate DH pipe or one of the pipes in a co-insulated triple pipe. This solution is however likely to create a need for a bypass flow in the street pipes.

The 2nd solution is based on the maximum cooling principle. After passing through the service pipe, the bypass water is directed to the bathroom floor heating and cooled down to 25 °C before it flows back to the return pipe. The benefit of this concept is that it uses the bypass flow continuously in the floor heating and replaces an intermittent flow due to a conventional floor heating control. In case there is no floor heating in the bathroom a towel heater may utilize the bypass flow. Such an application is called 'Comfort Bathroom (CB)' concept. This solution is also securing a flow in the street pipes and therefore does not need a bypass flow in the street pipes.

The 3rd solution is based on electrical supplementary energy. In large buildings with DHW circulation the need to keep the circulation at a minimum of 50 °C results in a high return temperature and requires a district heating supply temperature of more than 55 °C. This can be avoided by use of a heat pump that cools the district heating supply from 50 °C to 20 °C and heats the circulation loop to 55 °C. Figure 4-8 shows the schematic to use micro-heat pump to compensate the heat loss in the DHW circulation loop and keep the pipes temperature at 50 °C. The benefit of this concept is that the district heating flow to the heat pump also secures the instantaneous DHW heating of the heat exchanger. This solution does not require bypass in the street pipes.

4.3.3 Network circulation to eliminate street bypass

The precondition to eliminate service pipe bypass with the solutions described in chapter 4.3.2 is that the temperature at the street pipe should be kept above the minimum street set-point temperature (for example 50 °C). The street bypass is used to circulate DH water at the end of the street (normally is the location for the critical user) in order to keep the minimum DH supply temperature along the whole distribution network. Similar to the service pipe bypass, the street bypass water mixes with return water and

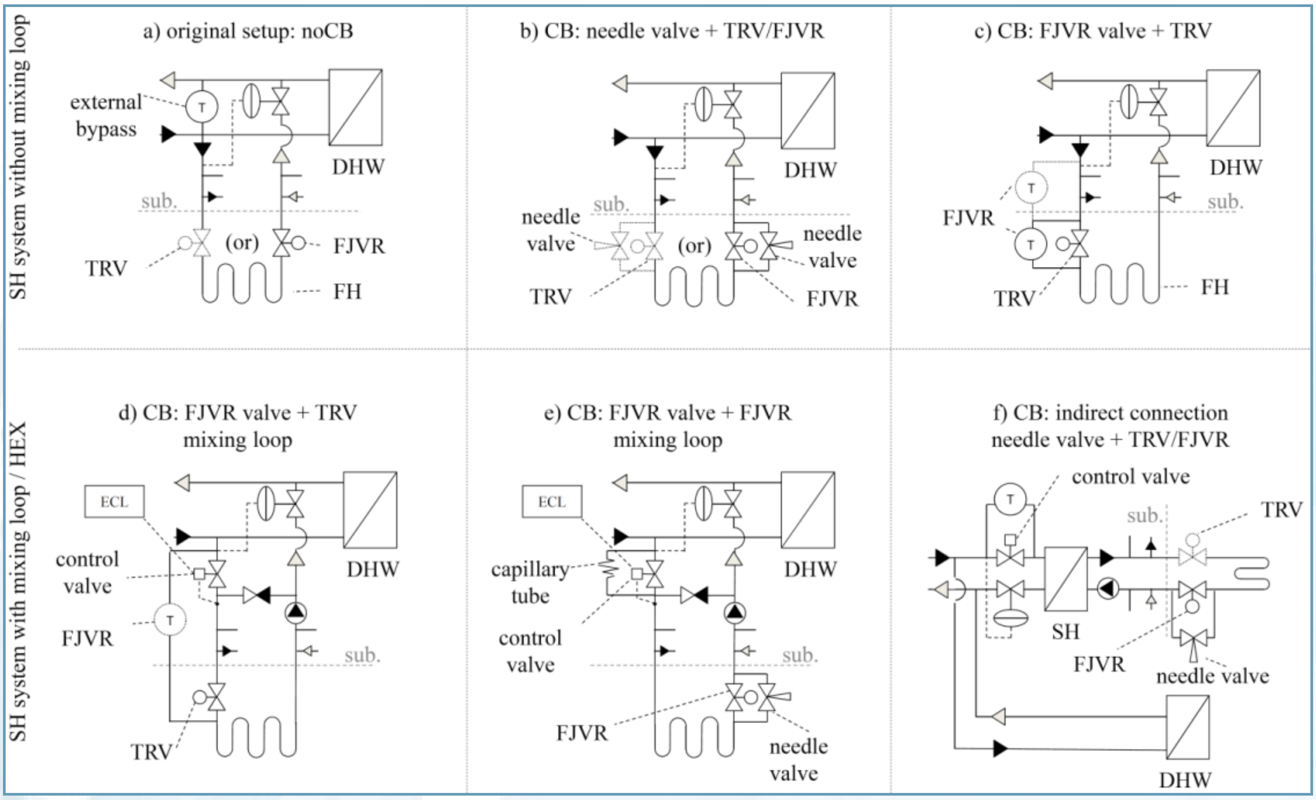

Figure 4-7 Comfortable bathroom concept (Brand 2014)

increases the network return temperature. One solution to avoid street bypass is to connect the branch shape network into the loop network. Such network configuration allows DH supply water circulate along all street pipes. The supply water flows back to the plant instead of mixing with return water. All street pipes can be kept warm if the circulation water temperature at the plant is set as the minimum street set-point temperature. The hydraulic implications for that setup would be that the pump at the plant drives the flow passing through the dense area first then the sparse area. It would get more resistance if flow in opposite direction. A case study to apply the network circulation to eliminate street bypass was performed for a DH system at Viborg, Denmark. Figure 4-9 and Figure 4-10 show the original network and the circulation. A detailed network simulation was performed with TERMIS (Schneider 2017). The simulation results indicate that significant amount of energy saving can be achieved when the supply water is kept flowing through the entire network. The heat loss saving is achieved with a cost of increased network differential pressure, pumping power, pipe length and adding local circulation pumps and valves to balance the flow in the network. With careful placement of connection pipes and adjustment for the flow balance, the increased power consumption of the pumping is negligible comparing with the heat loss savings. The length of connecting pipes, however, depends on the network topology thus needs specific analysis for each individual network.

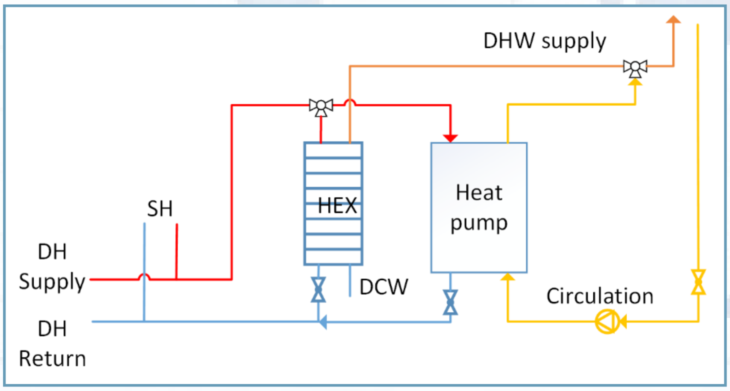

Figure 4-8 DHW system installing a central heat exchanger combined with heat pump (Yang 2016)

4.4 Domestic hot water supply

A well-designed and functioning DHW system should meet several criteria which include consumer comfort, hygiene, energy efficiency and effective cooling of the supply

Figure 4-9 Original network and removed street pipes

Figure 4-10 Circulation network

(Lund et al. 2014, Brand 2013, Yang 2016 and Bartram et al. 2007).

4.4.1 European regulations and guidelines for DHW preparation

In the context of drinking water installation the European regulations EN 806 (EN 806-1:2000 and EN 806-2:2005), and EN 1717 (EN 1717:2011) formulate a minimum standard and represent the greatest common denominator of European countries. The EN 806 provides recommendations for the planning of drinking water installations and is applicable for new installations, alterations and repairs.

The regulation EN 1717 (EN 1717:2011) is a guideline to protect drinking water from contamination in drinking water installations and contains general requirements for safety equipment to prevent contamination of drinking water. The technical report CEN/TR 16355:2012 (Allegra et al. 2011) provides basic information about the conditions for Legionella growth in drinking water installations in accordance with EN 806 (EN 806-2:2005) series up to the draw-off points and gives recommendations for preventing the growth of Legionella in these installations. Additional or country-specific regulations are given in section Appendix A: National Standards and guidelines on domestic hot water of IEA DHC participating countries. In particular temperature levels are an important issue regarding DHW preparation based on LTDH due to hygienic reasons (e.g. temperature interval of legionella growth risk). The temperatures at the outlet side of central DHW preparation units with and without DHW-storage as well as at the tapping point differ from country to country (Dalla Rosa 2014). However most of the European countries follow the guideline EN 806 - Specification for installations inside buildings conveying water for human consumption (EN 806-1:2000 and EN 806-2:2005) and CEN/TR 16355:2012 - Recommendations for prevention of Legionella growth in installations inside buildings conveying water for human consumption (CEN/TR 16355:2012 and Allegra et. al. 2011). According to these guidelines it is suggested that the water temperature should not exceed more than 25 °C for domestic cold water (DCW) and should not be less than 60 °C for domestic hot water (DHW) 30 seconds after fully opening of a sampling point. In addition to temperature levels more requirements for water installations are also specified. It is determined that systems of heated water must be designed in a way that the risk of scalding is low (CEN/TR 16355:2012 and EN 806-2:2005).

Regarding the risk of scalding for kindergartens, schools and senior citizen residences lower temperature levels are required. Furthermore, the EN 806 contains requirements for the distribution of DCW and DHW. Distribution of domestic cold water for low sampling or rare use must not be installed at the end of a long line. Furthermore, these pipes must not be laid close to pipes providing hot water in one shaft or channel. In

Table 4-1 Overview of small and large DHW systems (DVGW W551 2004):

Definition	Building type	Storage volume	Piping volume	Other requirements
small system	Single and multifamily buildings	no requirement	no requirement*	-
	Other buildings	< 400 litres	≤ 3 litres	-
large system	All buildings	> 400 litres	≤ 3 litres	-
	All buildings	> 400 litres	> 3 litres	installation of a circulation
	All buildings	< 400 litres	> 3 litres	installation of a circulation
*Pipes from DHW unit to tapping point				

case of DHW distribution national or local regulations to prevent the growth of Legionella must be respected. In addition hot water systems should have the facility to increase the temperature of the system at any point to 70 °C for disinfections purposes.
As an example for the distinction between application in single and multi-family houses but also for commercial buildings the German guideline (DVGW W551 2004) is used. The regulation considers storage tanks and piping volume. Furthermore a distinction between small and large systems with regard to Legionella risk is made.
The table above contains an overview of the requirement with regard to German guideline DVGW W551:
As can be seen from above and Table 4-1, these guidelines are aimed at traditional DHW installations with large DHW volumes. These regulations do not consider the new principles and very low DHW volumes applied in 4th generation district heating (Lund et al. 2014). Typical DHW units with storage tanks used in connection with DH are discussed in chapter 4.4.2.

4.4.2 Domestic hot water units

DHW installations should be designed with focus on energy efficient devices. The factors which influence DHW system energy efficiency include district heating supply and return temperature, heat losses from heat exchanger, storage tank and pipes, and thermal bypass set-point.
Effective cooling of the supply corresponds to large temperature drop in the consumer end. With improved DH water cooling, each unit of DH water brings more energy content. This will reduce the plant pumping power. Meanwhile, effective cooling leads to smaller network return temperature and smaller network heat loss. The heating plant thermal performance can be improved if the low temperature return water can be used for flue gas condensation.

Common DHW units with storage tanks used in connection with DH

Typical units with storage tanks which are connected to DH that can be found all over Europe are the DHW charging application and the DHW cylinder application.
Using a DHW charging application DHW is heated in a heat exchanger and let into a storage charging tank (see Figure 4-11). To maintain the desired temperature during idle time, the water temperature at certain location above the bottom, typically 1/3 of the volume, is monitored and if the temperature goes below a certain set point the water at the bottom of the storage tank is circulated through the heat exchanger. This will ensure that there will be sufficient amount of hot water available in the tank at the same time as adequate cooling of the DH supply is achieved. The storage charging tank is especially suitable for special applications, e.g. commercial buildings where the peak load of DHW is high.

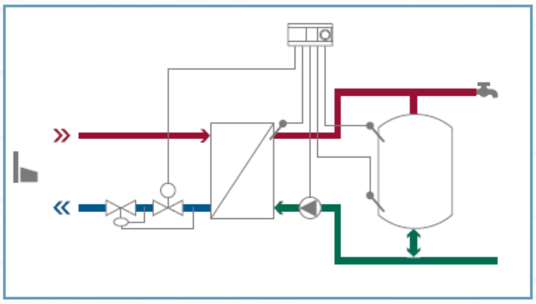

Figure 4-11 DHW charging application © Danfoss

This DHW preparation is normally used in combination with heating.
Areas of use:
- One-family houses
- Multi-family houses
- Commercial buildings

Typical markets: Central, South and Eastern Europe
Another option is using DHW cylinder application (see Figure 4-12). DHW is heated in a cylinder by an internal heating coil. DHW cylinder application is typically applied in decentralized boiler applications, it is not recommended in connection with DH systems due to generally high return temperatures compared to storage charging applications. This is not of a big concern in decentralized boiler with small distribution network. In contradiction in large distribution networks, as DH, it is leading to big heat losses.

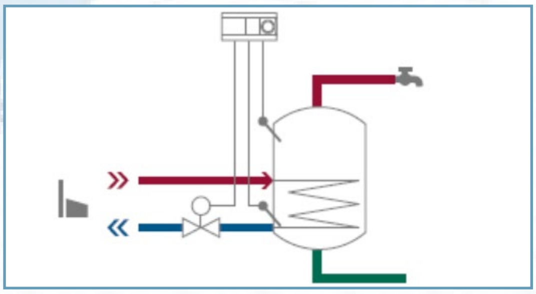

Figure 4-12 DHW cylinder application, not recommended to be used in district heating systems © Danfoss

This DHW preparation is normally used in combination with heating. It is not recommended in DH systems, especially not in LTDH.
Areas of use:
- One-family houses
- Multi-family houses

Typical markets: Germany, Italy, Austria and UK.
Once the DHW capacity of the storage tank has been used, it needs time to be recharged. In the event of DH interruption for short periods of time, the storage charging tank can supply the remaining capacity of DHW. However, large-volume storage tank increase the risk of bacterial growth and need additional maintanance (Danfoss 2017). Furthermore storage tanks have a large space requirement and large heat losses. Due to these DHW storage tanks are not recommended in LTDH.

DHW units for implementation in LTDH

There are two types of DHW units used for LTDH: instantaneous heat exchanger unit (IHEU) and DH storage tank unit (DHSU). The heat exchanger of the IHEU physically separates the DHW and DH water. IHEU produces DHW instantaneously when the hot water tapping is on. The DH supply water in the primary side passes through the heat exchanger and is cooled by the cold water from the secondary side. On the secondary side, the cold water is heated up to the desired temperature and supplied to the tapping point for consumer use. The application can supply an unlimited amount of hot water at a constant temperature, which is prepared close to the tapping point when demanded and hence reduces the risk of legionella and other bacterial growth. The total DHW installation volume should be designed to be less than 3 liters (DS/CEN/TR 16355 2012). Figure 4-13 shows the schematic of the IHEU with dp-controller and thermostatic and proportional DHW controller.

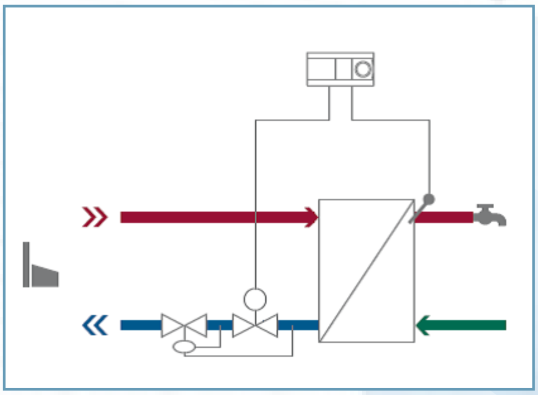

Figure 4-13 Instantaneous heat exchanger unit (IHEU) © Danfoss

This DHW preparation is normally used in combination with heating.
Areas of use:
- One-family houses
- Multi-family houses
- Commercial buildings

Typical markets: Almost all markets.
In DHSU, the storage tank is installed on the primary side and acts as a buffer to the secondary side. DH is drawn from the top of the storage tank and exchanges heat through the heat exchanger on the secondary side. As the storage tank in the primary side, it is feasible to supply low-temperature to the DHSU. Figure 4-14 shows the schematic of DHSU.

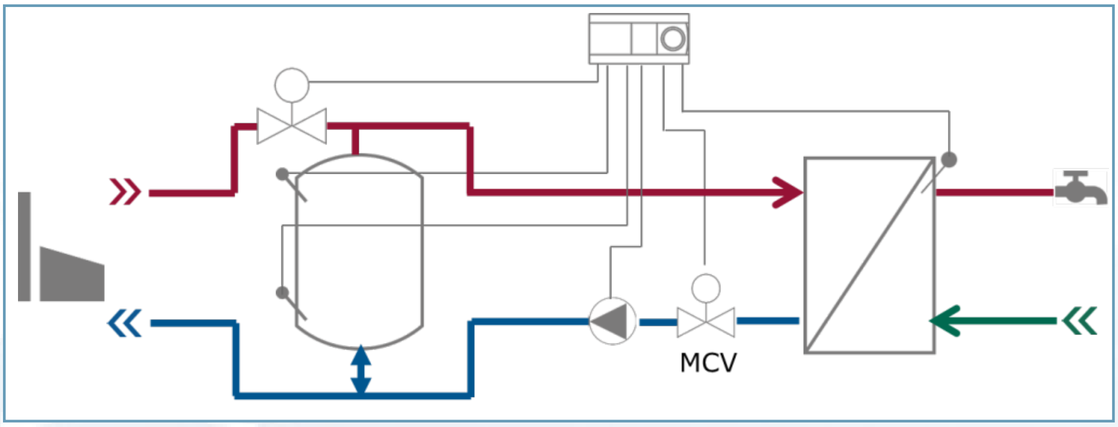

Figure 4-14 District heating storage unit (DHSU) © Danfoss

Both IHEU and DHSU can work at low-temperature without the risk of Legionella. Due to the storage tank buffer effect, DHSU can reduce the connection capacity and thus apply smaller diameter service pipes at the cost of additional heat loss from the storage tank. On the other hand, IHEU has less standby heat loss and is more compact and less costly.

4.4.3 Legionella treatment solutions

DHW is often supplied by DH with centralized hot water production and long distribution distance. LTDH reduces the network forward temperature to the threshold value of ensuring hygienic DHW supply. One of the key issues in LTDH is how to supply DHW at greatly reduced temperature without the risk of Legionella.
To ensure safe supply, many countries regulate the minimum DHW supply temperature and recirculation temperature. A well-designed and functioning DHW system must fulfill the requirements for hygiene, thermal comfort and energy efficiency. The major concerns with DHW preparation are hygienic and health risks, where the health risks result from bacteria growth in the water (e.g. appearance and growth of Legionella pneumophila). In general the bacteria risk is present when the DHW temperature is below 50 °C, as shown in Figure 4-15.
For all practical purposes 50 °C is high enough for human hygienic needs, e.g. dissolving food fats in dishwashing. Legionella growth at 50 °C is confined. This temperature is also low enough to avoid scalding of human skin, which can occur at temperatures above 65 °C (Frederiksen and Werner 2013). Except the temperature, the Legionella multiplication in a DHW system is influenced by the type of DHW installations (configuration of the pipes of hot water supply and recirculation, pipe dimension and pipe materials), age of the piping systems, scaling and presence of biofilm, etc. (Yang 2016).
In general, the Legionella treatment solutions include thermal treatment, chemical treatment, physical treatment and other alternative methods. Such treatments aim at either killing the bacteria present in the water or prevent the spread of Legionella by limiting the bacteria multiplication within a safety margin (Yang et. al. 2015).

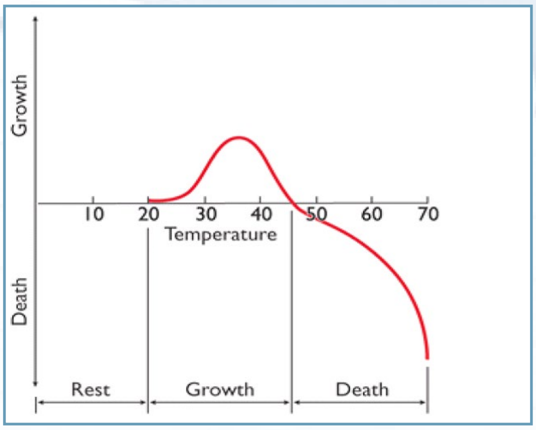

Figure 4-15 Legionella bacteria growth/ decay rates as a function of temperature (Frederiksen and Werner 2013)

Thermal treatment

Legionella bacteria can be killed rapidly at high temperatures. Thermal disinfection through heat flushing is considered as a systematic method which requires the whole piping system to be treated at the same time. The temperature at the distal faucet should be elevated to no less than 60 °C. Thermal

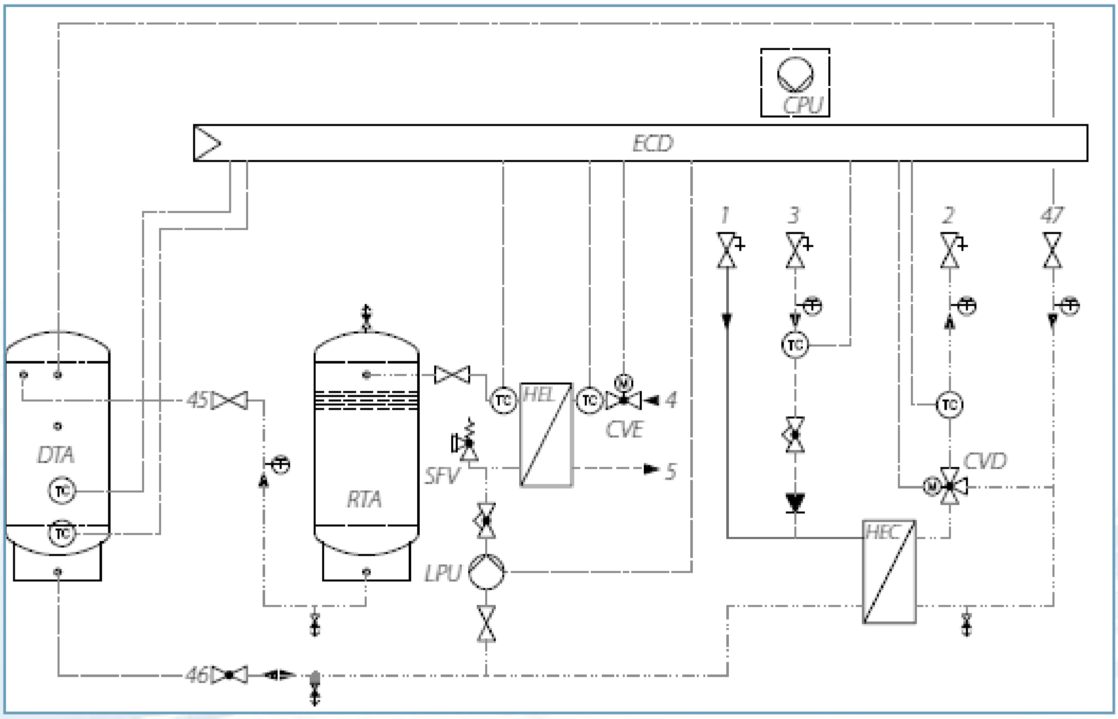

Figure 4-16 Domestic hot water thermal clean system © Danfoss

disinfection is normally used as an efficient short-term treatment to control a Legionella outbreak. It can be combined with other treatment solutions (like chemical treatment) for long term effect. Figure 4-16 shows the DHW thermal cleaning system.
In case of thermal disinfection to counter legionella contamination WHO recommends a heat shock at 70 °C for 30 min. which is to be repeated at least twice during 72 hours (Allegra et. al. 2011). For the hot water at the storage tank, the temperature should be lifted to 70-80 °C and kept at this temperature level for 72 hours to eradicate the bacteria in the tank (Campos et. al. 2003).

Chemical treatment

Chemical treatment rinses the piping system with chemical biocides to kill off legionella. It is widely used for bacteria disinfection in water system. Chemical treatments include ionization, oxidizing agents and non-oxidizing agents. Effective chemical treatment requires precise control of dosage concentration. After the treatment, the system is required to be thoroughly flushed to remove corrosive and possibly toxic chemicals.
Ionization uses two different ionized metals to disrupt the permeability of the bacteria's cell wall and subsequently denatures proteins and cellularlysis. The most widely used electrodes are copper /silver.
The oxidizing disinfectants are mostly used in chemical treatment solutions. It includes various types like chlorine, chlorine dioxide, ozone, monochloramine and hydrogen peroxide. Among these, chlorine is one of the most widely used oxidizing disinfectants in different water systems.

Figure 4-17 UV Sterilization (Walleniuswater 2017)

Physical treatment

Physical treatment disinfects water without chemical addition and leaves no residuals and odor after treatment. It includes membrane filtration and UV sterilization. UV Sterilization cleans water with the ultraviolet light at a wavelength of 254 nm. The disinfection process works by damaging the bacteria DNA replication, similar to an open stream exposed under sunlight. The filtration membrane has fabric structure with a large amount of microscopic pores. The membrane retains bacteria, but allows vital minerals to go through. It has superior disinfection efficacy and is commonly used for physical treatment of nosocomial Legionellosis in high-risk patient care. Figure 4-17 shows the UV sterilization method.

Alternative solution

Chemical and physical treatments are normally independent of temperature level and thus can be applied in LTDH. The limitations of their application are the initial cost for disinfectant production, precise monitoring and control systems, and risk of corrosive and possibly toxic chemical residuals. Apart from chemical and physical treatments, alternative solutions exist for LTDH application.

For single family houses, the risk of Legionella can be controlled through confining the DHW volume in the secondary circuit. The DHW volume from the substation to the tapping point is designed below 3 liters (see DVGW W551 2004). This way, the circulation pipe is eliminated and DHW can be supplied safely at low-temperature.

Multi-story buildings are traditionally supplied from centralized heating units. The DHW supply pipe is kept warm through a circulation pipe to ensure consumers get warm water without excessive delay. The supply temperature is typically above 60 °C. To supply LTDH to multi-story buildings, one of the effective solutions is to use flat stations. As shown in Figure 4-18, a flat station is a small substation installed at each individual flat in the multi-story building to fulfill SH and DHW demand. Similar to the single family house, the 3 liter rule can be subsequently applied to multi-story buildings.

As described in 4.3.2, low-temperature DHW can be boosted on-site through auxiliary energy. The supplementary energy normally comes from electricity. It can be an electric heater in the storage tank, an electric heater after the DHW heat exchanger or a micro-heat pump combined with DH storage tank units. Such solutions can also be applied in ultra-low temperature DH systems. Another thermal booster system is using electric tracing. Such a solution is normally applied in multi-story buildings or buildings with a large volume DHW pipework to keep the supply pipe warm so that the circulation pipe can be eliminated. Figure 4-19 shows the electric tracing device and its use in DHW supply pipes. The circulation pipe can be eliminated through use of an electric heat tracing device.

The electric cable is attached outside of the DHW supply pipe to heat it. The electric energy consumption is self-regulated which is proportional to the temperature difference between the cable and the hot water. With an electric heat tracer, the total energy loss can be reduced by 40 % comparing with the system with circulation pipe (Yang et al. 2015).

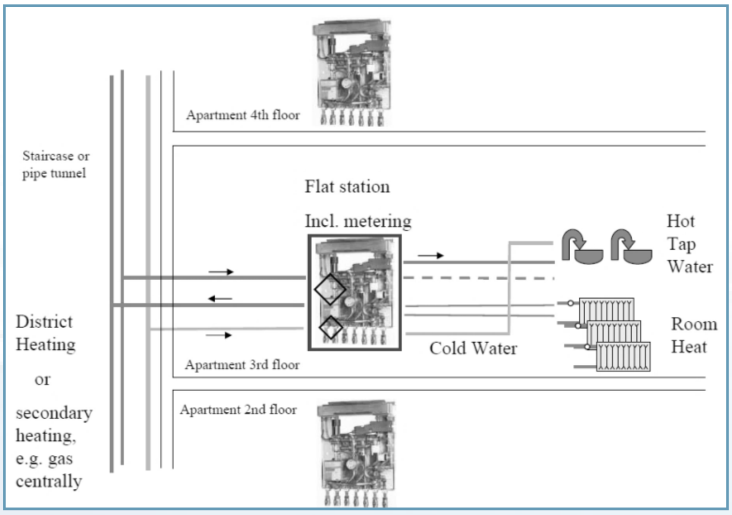

Figure 4-18 Flat station in multi-story buildings (Thorsen 2010)

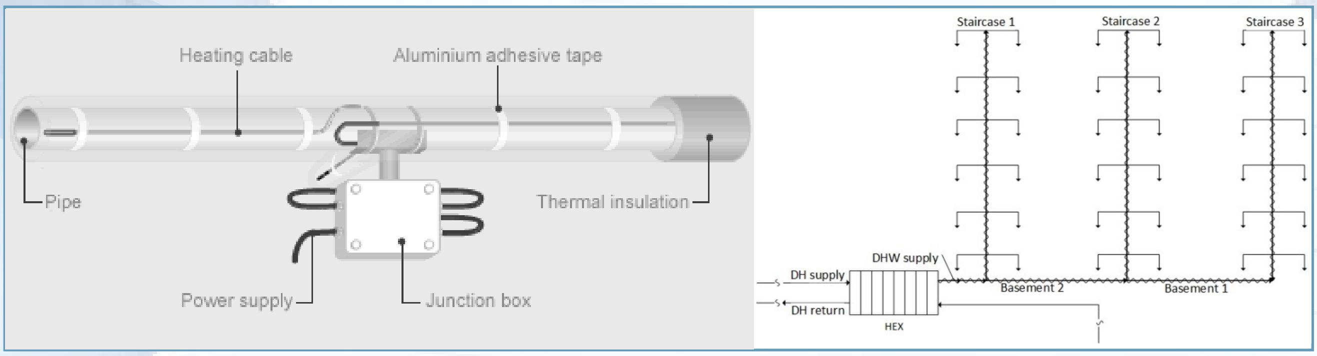

Figure 4-19 Electric heat tracing of domestic hot water pipe (Yang and Svendsen 2014)

DHW supply at ultra-low temperature

Beyond LTDH, it is possible to supply ultra-low temperature DH at temperatures below 50 °C to meet the residential building heating requirement. Such an application has the advantage to further reduce network heat loss and increase waste heat utilization. Cases are reported to use ultra-low temperature DH with different types of thermal boosters at the consumer substations (Yang et al. 2016).

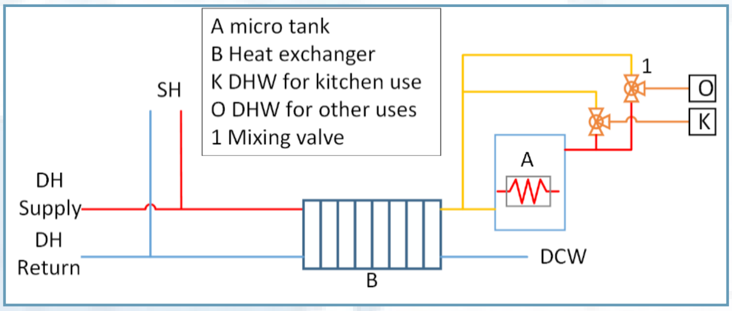

Figure 4-20 Schematic of electric micro tank system (Yang et al. 2016a)

Figure 4-20 shows the solution to use a small storage tank with electric auxiliary heater. The micro tank with immersed electric heater is installed on the consumer side. The DHW is preheated by ULTDH through the heat exchanger. Since the temperature of the preheated water is lower than the comfort requirement, one stream of the preheated DHW is further heated and stored in the micro storage tank. To meet the requirement of Legionella prevention, the DHW in the tank is heated to 60 °C by the electric immersion heater. When DHW draw-off occurs, the DHW from the tank is mixed with the hot water heated by the heat exchanger.

4.4.4 Conclusion

The low temperature district heating (LTDH) concept aims at reducing the supply temperature, while still fulfilling comfort requirements for domestic hot water and space heating. A well-designed and functioning DHW system must fulfill the requirements for hygiene, thermal comfort and energy efficiency. One of the major barriers to implementing LTDH is the increased Legionella risk with supply temperatures close to 50 °C. A literature survey was conducted in order to identify DHW supply regulations in IEA DHC participating countries. Most of the European countries more or less follow the European guidelines EN 806-1:2000, EN 806-2:2005 and EN 1717:2011 which differentiate between small and large systems but do not consider the very small volume (<3 liters) systems that are used in LTDH schemes. Recommended operating temperatures for large systems (e.g. multi-family house, hotels, etc.) are between 55 °C - 60 °C and temperatures in small systems (e.g. single family house) should not be below 50 °C. Further DHW installations should be designed with focus on energy efficient devices. There are two types of DHW units used for LTDH: instantaneous heat exchanger unit (IHEU) and DH storage tank unit (DHSU). Both IHEU and DHSU can work at low-temperature without the risk of Legionella.

IHEU has less standby heat loss and is more compact and less costly compared to other solutions as DHSU. On the other hand Due to the storage tank buffer effect, DHSU can reduce the connection capacity and thus apply a smaller diameter service pipe at the cost of additional heat loss from the storage tank. One of the key issues in LTDH is how to supply DHW at greatly reduced temperature without the risk of Legionella. For that reason different legionella treatment solution have been described and compared. In general, the Legionella treatment solutions include thermal treatment, chemical treatment, physical treatment and other alternative methods. Such treatments aim at either killing the bacteria present in the water or prevent the spread of Legionella by limiting the bacteria multiplication within a safety margin.

4.5 Control of space heating

4.5.1 Supply temperature for LTDH

It has been proven that LTDH can meet space heating (SH) demand for both low-energy buildings and existing buildings with floor heating (see chapter 7 and Brand 2014). For existing buildings with the existing radiators, LTDH can meet SH demand for a certain amount of time of the year, while the supply temperature needs to be increased during cold winter period. To ensure consumer thermal comfort while saving energy and reducing network return temperature, the hydronic system in the SH loop need to be properly designed and functioning.

4.5.2 Control of SH supply and return temperature

In general there are three connection principles for connecting the space heating installation with the DH network,

a) indirect connected,
b) direct connected with mixing loop and
c) direct connected.

Figure 4-21 shows the indirect connected SH system (Thorsen and Gundmundsson 2012).

Radiator space heating control

Although space heating control when applying LTDH is in general the same as when applying traditional DH, there are some points that differentiate. Due to the reduced supply temperatures, it becomes very important to achieve accurate control to limit the flow rate and achieve the design cooling of the supply.
To minimize the risk of overflow in radiators thermostatic radiator valves (TRV), a presetting function should be used. The purpose of the thermostat function is to adjust the flow to achieve the desired room temperature. The purpose of the pre-setting is to limit the maximum flow through the valve at design condition.
Properly set pre-set function will significantly increase the hydraulic balance in the heating loop.
To ensure proper operating condition for the TRV's, it is important to install a differential pressure controller. The differential pressure controller will ensure a stable differential pressure at the correct level across the heating installation.
To limit the impact of wrong setting of the TRV, a thermostatic return limiter can be installed at the radiators. The purpose of the return limiter is to ensure minimum cooling of the supply. The function of the return limiter is that it closes if the outlet from the radiator is higher than the set point. Most of the year a return temperature of 25 °C can be achieved but in cold periods higher temperatures have to be accepted.
Therefore it is proposed to develop new type of smart thermostatic radiator valve with a return temperature sensor. Such a TRV could secure a low return temperature even if the TRV is not used in an optimal way. For this smart TRV the allowable return temperature need to be adapted according to the outdoor temperature. Furthermore, the radiators need to be designed to deliver low desired return temperatures at peak demand (they need to be big enough) otherwise insufficient heat is delivered to the room at cold outdoor temperature and peak demand.

Floor and wall heating control

In case of floor heating installation, the maximum supply temperature requirements are typically around 40-45 °C, which causes no problem for the application of low temperature DH.
As with radiator controls, it is important to apply differential pressure controllers to achieve the optimum operating conditions for the floor heating installation. The flow rate is typically regulated by a room thermostat.
To ensure minimum cooling of the supply return temperature limiters should be applied.

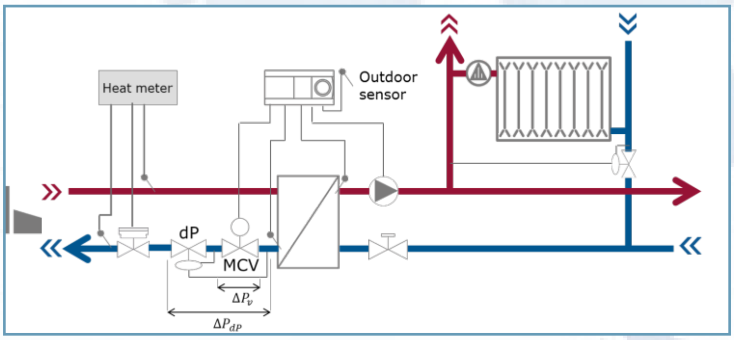

Figure 4-21 Indirect connected SH substation © Danfoss

4.5.3 Mass flow control

In a traditional DH system, in the secondary side, i.e. the building heating system is operated using self-acting control valves and a circulation pump. The supply water temperature on the secondary side is adjusted as a function of the outdoor temperature to meet a certain heating demand. To keep the supply water temperature at the desired value, the primary side flow to the heat exchanger is controlled using a motorized valve. Pressure and the supply temperature in the whole DH network are generated and adjusted at a centralized location, which is usually the heat production plant. Actual customers' pressure differences and supply water temperatures depend on their

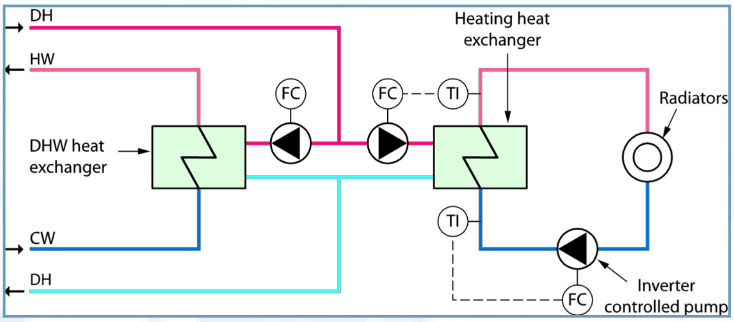

Figure 4-22 Mass flow concept. The secondary side and primary side pumps are controlled to receive equal flow rates and temperature differences for primary and secondary sides of the heating heat exchanger. (Laajalehto et al. 2014)

locations on the network.

The mass flow control concept refers to a system where both the primary and secondary side flows are adjusted with inverter-controlled pumps instead of control valves in ring networks (Kuosa et al. 2014). The flow adjustment is carried out by controlling the rotation speed of the pumps. When heat is not required in a building the speed of the pump is about 10 Hz and the pressure losses of the substation block the flow through the substation.

One possible philosophy of controlling the pumps is presented in (Laajalehto et al. 2014) where secondary side pump is controlled in order to receive a constant return temperature from radiators. In modern systems TRVs or other mechanics to individually adapt the heat supply to the heat demand are commonly used to control the flow. For the pump control philosophy water flow on the primary side of the heating heat exchanger is adjusted in order to have a constant secondary side supply temperature, which is done by changing the rotation speed of the primary side pump. Idea of the new pumping system is not only to overcome pressure losses in the substation but also to function as weather compensators by adjusting the secondary side temperature levels according to the outdoor temperatures.

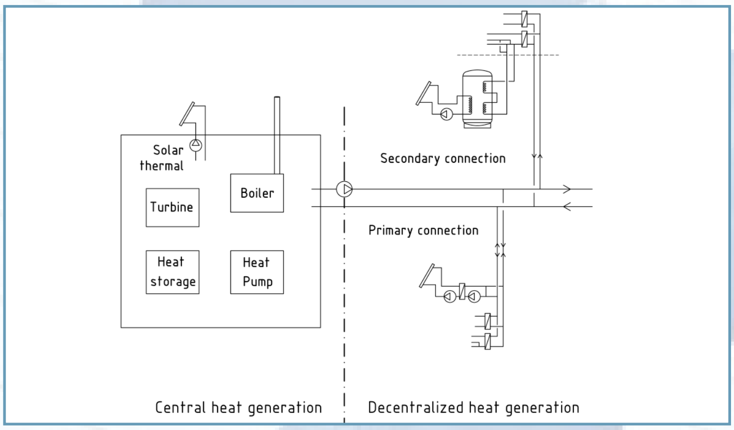

Figure 4-23 Examples of decentralized solar thermal systems with primary and secondary connection (Lennermo et al. 2016).

4.6 Integration of small scale decentralized heat sources

District heating systems have historically consisted of large-scale conventional production units owned by energy companies. As the knowledge and awareness of environmental problems (e.g. climate change and air pollution) grows, there has however been a change in the approach (see chapter 3). This has led to a demand for higher integration of renewable energy in our energy supply and more resource efficient energy systems, as LTDH schemes (Lund et al. 2014; Frederiksen and Werner 2013).

There is a huge potential to supply district heating systems with heat from small, distributed sources such as industrial surplus heat, solar thermal systems, crematories and cooling machines in offices, sport facilities and grocery stores. The main advantage of LTDH is that especially waste or renewable energy sources with low temperature levels can be efficiently integrated into the schemes (see chapter 2). These sources are utilised directly where ever possible. Heat pumps are used with high efficiencies to boost the temperature level if the temperature levels of the source are not sufficiently high for the supply. There is a growing interest in the integration of solar thermal collectors in the heat supply of district heating systems in the so-called solar district heating in a number of countries (Dalenback 2015, Schäfer and Mangold 2015, Rühling et al. 2015 or Lennermo et al. 2016). Another idea is that customers buying heat from the DH companies are also able to sell heat to the grid. Prosumer is a concept that is becoming more and more common in order to describe a district heating customer

that both buys and sells district heat. Prosumers may be part in future smart energy systems (Brange et al. 2016 and Lennermo et al. 2016).
There are many questions that must be answered before a decentralized heat source can be used in a DH system. An important point to start with is to decide what kind of heat source shall be used and where to connect it to the grid. In big DH systems it is not a big technical problem to integrate a small heat source into the scheme as long as the feed-in temperature is sufficiently high for the supply. But if there are many feed-in plants or one feed-in plant is large in comparison to the DH system, the proper regulation and dimension becomes more important.

4.6.1 Connection variants for decentralized feed-in

There are mainly three possible/common variants for the feed-in of heat from decentralized sources into district heating grids. In the following they are listed and described with their particular advantages and disadvantages. A schematic representation of the variants is shown in Figure 4-24. The combination of these variants and a transfer station is also possible (Schäfer and Mangold 2015).

Extraction from the return line and feed-in into the supply line (R/S)

The heat transfer medium is extracted from the return line of the district heating grid, heated by the decentralized source and fed-in into the supply line. The necessary temperature difference is dependent on the operating conditions of the district heating grid and on the specifications of the grid operator. This will result in changing operational conditions. The mass flow in the transfer station has to be adjusted according to the requirements to the feed-in temperature. The pressure difference at the feed-in point can be high for this variant and could result in pressures up to several bars depending on the actual location in the grid. This may result in a high energy demand for the mandatory feed-in pump. The grid operators commonly prefer this variant as the return temperature in the grid is unchanged, which avoids temperature strain on the pipe

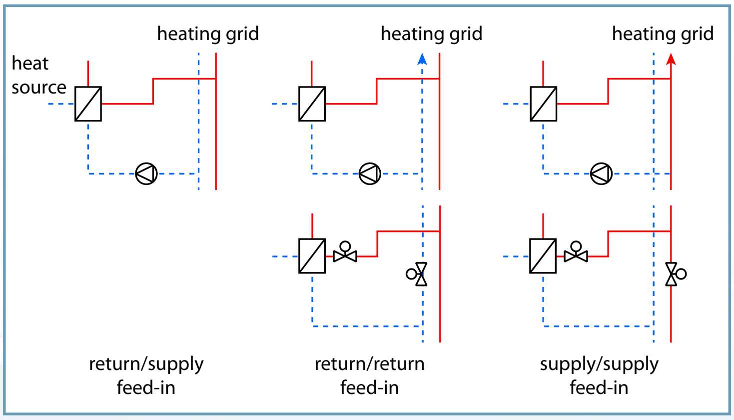

Figure 4-24 Schematic representation of the three feed-in variants with pumps (upper row) or with an adjustable flow resistant (lower row) (Schäfer and Mangold 2015)

network and it does not influence the heat extraction efficiency of other heat sources, and the supplied heat is provided at a direct useable temperature level. This variant is feasible in most applications.

Extraction from the return line and feed-in into the return line (R/R)

In this variant, heat transfer medium is extracted from the return line of the district heating grid and supplied back into the return line after the heating process. The limits of the temperature rise are commonly set by the district heating operator (common are 5 K to 15 K). The mass flow needs to be regulated according to the requirements to the feed-in temperature. The pressure difference at the feed-in point is relatively low. The comparable simple regulation of the mass flow can be done via a pump or via an additional adjustable flow resistant in the return line of the district heating grid. The flow direction of the heat transfer medium needs to be known for the correct design of the connection and the position of the pump. Grid operators try to avoid additional flow resistances in their grids since they result in higher energy demand for the central supply pump for the grid. The use of pumps in the decentralized feed-in connection is not possible for grids with changing flow directions, e.g. in a small loop of the network. The changing flow direction would mainly be an issue in a small loop of the network. Because of the comparable low temperature differences this variant is preferable for decentralized heat sources with high efficiencies for lower temperatures, as solar thermal plants and heat pumps. However, the grid heat loss will increase and there might be a negative impact on the central heat supply/generator by this connection variant because of the raised return temperature.

Extraction from the supply line and feed-in into the supply line (S/S)

In this variant the supply line is used instead of the return line, as mentioned above. The heat transfer medium is extracted from the supply line, heated and supplied back into the supply line. The allowed temperature increase is prescribed by the heating grid operator, similar to the R/R case 5-15K. Furthermore, additional heat losses will occur in the grid because of the increased temperature level in the supply line. The comparable simple regulation of the mass flow can be done via an additional pump (information about flow direction in the grid mandatory) or via an adjustable flow resistance in the heating grid. The resulting high temperature level for the feed-in will cause lower yields for decentralized heat sources with high efficiencies for lower temperatures, as solar thermal plants and heat pumps.
The last described variant, extraction from the supply line and feed-in into the return line (S/R) is seldom used and the last possible variant extraction and supplying to the supply line (S/S) is commonly not used, but discussed in detail and mentioned in (Lennermo et al. 2016 and Lennermo 2016).

4.6.2 Decentralized (waste-) heat sources

For the connection of a decentralized heat source to a DH system some details need to be considered. Few of the most important points are:

- Overall cost efficiency of the integration as well as cost and environmental impact/benefits of the new heat source.
- Possible feed-in temperature. The standard should be that the feed-in temperature is similar to the temperature setpoint of other plants in the DH system.
- Variation in heat power production. Production time, when and how many hours a day, a week and over a whole year.
- Possibilities to regulate the heat source are of advantage.

First after a careful assessment of the above mentioned issues the utilization of an additional heat source should be taken into consideration.

Solar thermal collectors

Depending on the collector type (flat plate, vacuum tube, etc.) solar thermal systems can produce the feed-in temperature in a wider range. In general, higher required feed-in temperatures are causing lower efficiencies in the solar thermal system. To maximize the yield it is important that the dimensioning and regulation of the system gives as low as possible return temperature to the solar collectors. The heat power production from a solar thermal installation varies a lot over the day, between days and over the year. Further, the heat output can vary a lot on where the plant is situated. The additional use of thermal storage devices may increase the plant utilization through decoupling of the supply from the solar plant and the demand of the district heating system. To get the most out of solar thermal system these heat plants are normally coupled with a large thermal storage, which can store the heat over one or more days and even between seasons.

Industrial waste heat recovery

Industrial heat recovery is commonly used from big industrial plants in a number of countries. But it is hard to find examples of installations from smaller plants.
Normally, boundary conditions for the use of waste heat from these plants are very individual and must be treated as such. On the one hand, there are systems with fixed excess heat power production and an annual operation for more than 8,000 hours. On the other hand, there are systems with fluctuations in the heat output, e.g. following a varying production. Lower required feed-in temperatures are a general advantage since the amount of waste heat is larger for lower temperature levels and more industrial processes might be connected to the DH grid. In case of very low waste heat temperatures heat pumps can be used to boost the temperature levels to the required feed-in temperature.

Waste heat utilization from compressor machines, chillers

Compression chillers need to emit heat from their condensers during operation. This waste heat can be utilized in DH systems, especially when the chillers are working continuously. Chillers operating continuously are used for example for cooling of data centers and supermarkets. In Viborg, Denmark, it is planned to utilize the waste heat from data center chillers (see chapter 5.3.3) (Diget 2015) example of waste heat from cooling units in supermarkets can be found for example in Høruphav in Denmark. (Thorsen et al. 2016)

Geothermal heat

The heat extracted by geothermal plants (here we are referring to shallow geothermal installations, it is from less than 100-meter-deep boreholes) can have a wide temperature range, in some cases the heat can be used directly and in other cases it may require to be raised with a heat pump. Geothermal plants are typically designed for supplying base load since they generally have initial investment cost but low operating cost and can be operated all year round.

4.6.3 Example of a district heating grid integrating decentralized solar thermal plants

As mentioned above, one commonly used decentralized heat generation technology is solar thermal collector. In (Hassine et al. 2015) detailed information on decentralised feed-in is given. In the example of the city of Ludwigsburg/Germany (see also chapter 7.2.2) a prosumer substation is applied in a local micro-net: During high solar yield the surplus heat generated in decentralized solar panels is transferred to the micro-net and vice versa when the solar heat is not sufficient (Hassine et al. 2015).

Figure 4-25 shows the hydraulic integration of the solar system for a typical substation in Germany. The components of the substation are the buffer storage tank with DHW preparation (middle/right) and a heat exchanger for grid connection. For simulation purpose the system is modified to become a prosumer system, a solar thermal collector and two additional heat exchangers have been added for feeding solar heat directly into the buffer (first priority of the control) or to inject the heat into the grid (when the tank is fully charged).

For single-family houses (SFH), the smaller (right) DHW storage tank with a capacity of 500 l is exchanged by an instantaneous heat exchanger. Otherwise, the heat exchangers in the two systems are identical. The larger DHW storage tank (left) is 825 l for SFH and 1,000-2,000 l for MFH.

Figure 4-26 shows the simulation results of operating the transfer station (SFH) in July. The supply temperature at the network node (dark blue) varies between about 130 °C (heat injection of surplus energy to the network) and 65 °C as a nominal supply line temperature during normal operation. The-

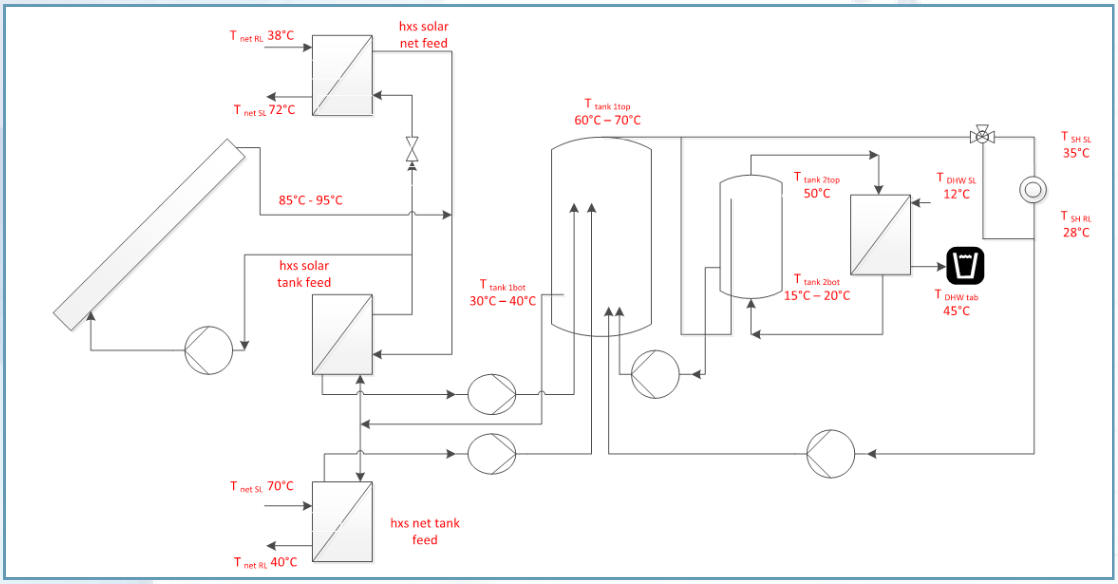

Figure 4-25 Hydraulic connection of decentralized solar plant to existing substation (MFH) (Hassine et al. 2015)

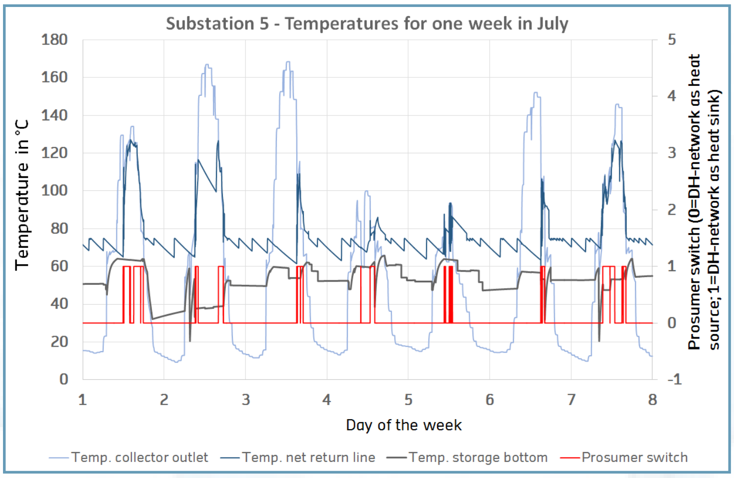

Figure 4-26 Thermal behavior of SFH prosumer substation for a week in July (Hassine et al. 2015)

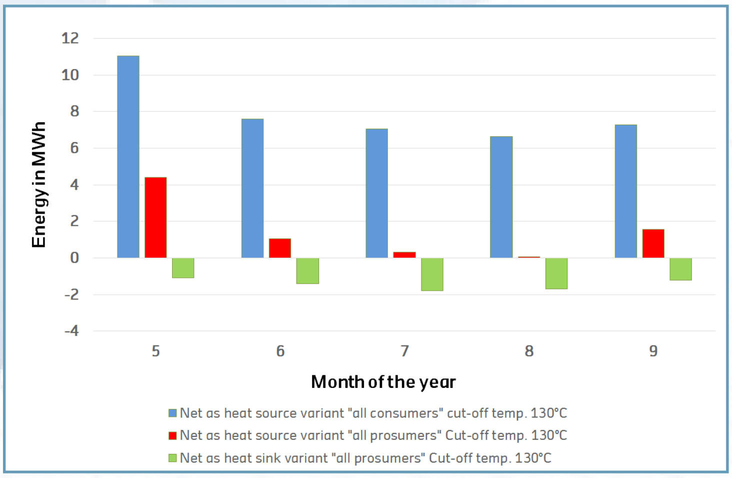

Figure 4-27 Details of energy or DH-network maximum collector outlet 130 °C (Hassine et al. 2015)

se excessive fluctuations might have an impact on the pipe network. The sloping lapse of the supply line temperature can be explained by the consideration of thermal losses of the network during operation and standstill. It can be seen that the grid has not been used as a heat source for the entire week of July (default value for consumer/prosumer switch = 0 also for standstill).

In the months of June, July and August, the amount of solar supplied heat to the grid (green bars) exceeds significantly the removal from the network, as shown in Figure 4-27.

More details of this project can be found in (Hassine et al. 2015).

5 INTERFACES AND COMMUNITIES

5.1 Introduction

In this chapter interfaces in the district heating systems context present different types of links between heat supply and demand of buildings by means of water-based systems. The technical and research field of the interfaces covers a broad range of issues as shown in Figure 5-1.
The challenge of the improved interfaces in district heating systems may be explained via so-called hard and soft issues:

- The hard issues cover the following topics: District heating network structures, requirements for consumer substations and buildings, and connection principles for distributed heat sources.
- The soft issues cover the following topics: technical and economical modelling of the distribution system, optimization between demand and generation side, innovative control concepts and energy measurement, transition of the existing DH grid to the LTDH grid, and new pricing and business models.

During the course of the project promising models, concepts, and technologies to meet the goals of future renewable based community energy systems have been collected and identified. Some of the relevant technologies have been described in chapter 4, as new pipe technologies, substation configurations, and renewable technologies. This section aims to provide an overview on the most relevant topics and issues related to the interfaces in the district heating community.
As possible to note from Figure 5-1, the interfaces issue is highly relevant for a successful implementation of the LTDH and thereby enabling transition to the renewable energy society and secure energy supply for future development of society. By introducing better interfaces between the demand and supply, DH systems can be transformed into a smart grid energy system on a district level.

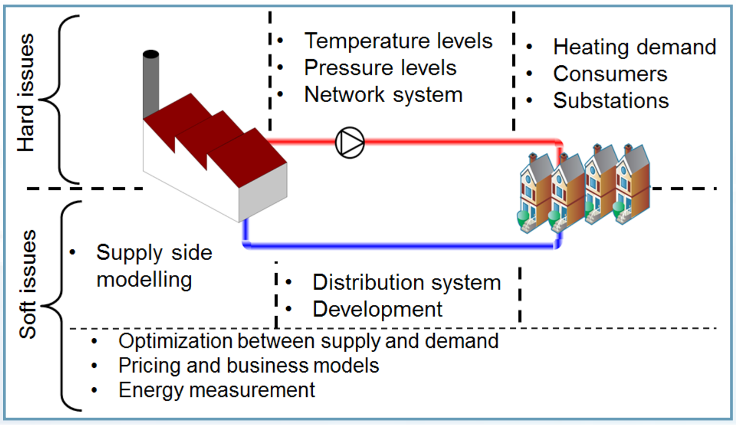

Figure 5-1 Big picture of interfaces in district heating systems

5.2 Predicting DH demand and future development

Energy efficiency in buildings has been an important topic since 1970 and has been widely recognized as an option to decrease energy use. For that purpose, different tools, methods, standards, and business models have been developed (Nord and Sjøthun 2014). The recast of the directive on the energy performance of buildings (EPBD) established the political target of nearly zero energy buildings (nZEB) for all new buildings by January 2021 (EU-Directive 2010/31). The topic of zero energy buildings (ZEB) has been important in the last years (Kurnitski et al. 2011, Nielsen and Möller 2012, Li et al. 2013, Marszal and Heiselberg 2011, Osmani and O'Reilly 2009). nZEB and ZEB have to be actively connected to the energy systems to fulfill their requirement. Regardless of the energy requirements for new buildings, most of today's buildings are existing buildings. Therefore, energy planning and management of the future integrated energy systems has to include a variety of different buildings. Due to different building purposes, occupant behavior, and operation and maintenance, building energy use is a complex system with emergent behavior (Guckenheimer and Ottino 2008). Therefore, forecasting future building heating demand should be based on stochastic methods (Andersen et al. 2000) and combination of statistical and physical methods (Lü et al. 2015).

An analysis on development of the heating demand until 2050 was made based on the Norwegian building statistics of the current residential building stock and forecasts for the residential building development in Norway found in (TheLowEnergyCommittee 2009). The aim of the analysis was to show change in total heat demand due to energy efficiency in buildings and market penetration of the new houses. Based on the current statistics, there are 61.7 % of older buildings, 35.1 % of intermediate buildings, and 3.1 % of low energy buildings, and 0.1 % of passive houses. Linear models for the building stock development were assumed based on (Li et. al. 2015), as shown in Figure 5-2. The models assumed that the growth rate for new buildings is 1.33 %/year, renovation rate is 1.5 %/year, and demolition rate is 0.6 %/year (TheLowEnergyCommittee 2009). An imaginary area presenting a residential building stock with a heat demand of 80 MW was introduced.

By using the results on the heat demand, explained in (Ingebretsen 2014) and linear models for the building stock development shown in Figure 5-2, a projection of the heat demand development until 2050 was obtained as shown in Figure 5-3. It should also be noted that in Figure 5-3, increase of the building stock was not counted, which could change the total heat demand. In the case of the building stock increase, the total heat demand would be the same or higher in the future regardless of the market penetration of low energy and passive houses. In addition, Figure 5-3 gives heat demand in the case of ambitious and conservative development of the building stock. A change of ± 20 % deviation of the normal development, given in Figure 5-2, was introduced to produce ambitious and conservative development, respectively.

From Figure 5-3 it may be concluded that even with the ambitious scenario for the residential building development, the total heat demand would decrease by about 18 % in 2050 compared to the current heat demand. This means that the DH would still be needed for most of the buildings in 2050. Based on this, the LTDH is expected to be a promising heat technology for the future.

In the analysis in Figure 5-2 and Figure 5-3, market penetration of nZEB was not included. However, a study shows that the excess heat from nZEBs can benefit DH systems by decreasing the production from the centralized units (Nielsen and Möller 2012). Research on the distribution and investment issues of the DH systems show that the most favorable conditions for the further development appear in large cities and that in these areas there is low risk for reduced competitiveness due to reduced heat demand. Hence, reduced heat demands are not barrier for DH in the future (Persson and Werner 2011). Regarding energy sources for the DH in the future, a thorough research on sustainable heat potentials at the European level shows that there is enough available heat, but policy measures are necessary for realization of all the potentials (Persson et al. 2014).

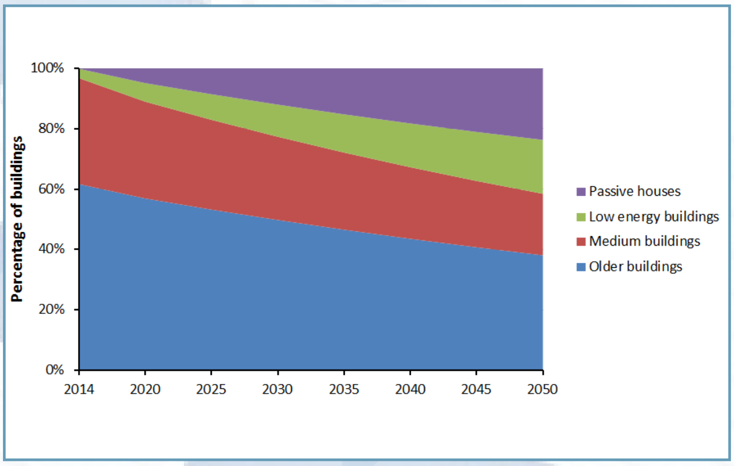

Figure 5-2 Forecasting of the building stock development in Norway

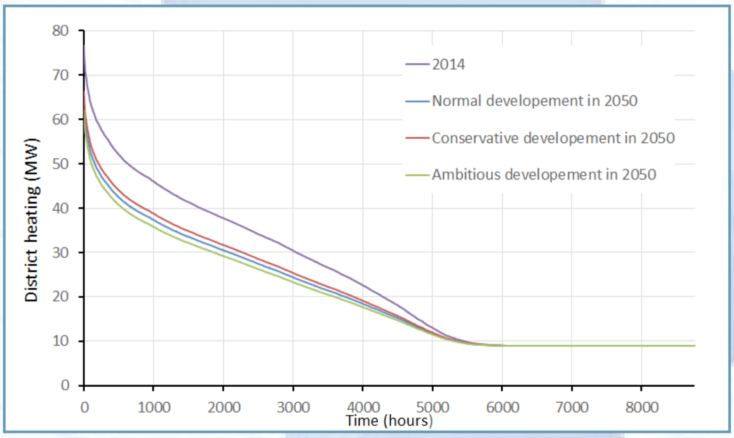

Figure 5-3 Heat demand development for the residential building stock in Norway (Fossmo and Skrauvol 2016; Nord et al. 2016)

5.3 Distribution and development issues

One of the main ideas of the LTDH is to enable easy integration of the renewable distributed energy sources. Renewable energy and waste heat sources together with heat storages may be organized as decentralized or distributed. Decentralized systems imply that heat supply is divided into several plants geographically decentralized, but centrally organized. The situation with distributed energy sources will appear when single buildings, industrial plants, and any other actors are enabled to deliver their renewable or waste heat to the DH system. To enable a well-functioning and renewable DH system with many actors, good knowledge on DH operation, component behaviour, and requirements for the grid connection are highly necessary.
All these issues are important to identify in a correct way a cost and responsibility share in the system. The distribution of costs of heat losses should be treated in a simple way, since it is to be accepted that heat is lost in the distribution network and all consumer need to share that cost.

5.3.1 Heat losses and pipe reliability issues

Reliable distribution system is highly necessary to realize the ideas of the LTDH and stay competitive on the energy market. Therefore, knowledge on the heat losses and pipe reliability is highly necessary.
It is difficult to identify high quality data on heat losses in the DH systems for different plants. Some pipe producers provide small calculation programs to calculate heat losses in pipes. However, pipe producers are able to provide information about the heat loss coefficient of their pipes. The heat loss coefficient can then be used to estimate the heat loss under various operating conditions.
A methodology for the pipe network cost models including pipe heat losses and heat density has been suggested in (Kristjansson and Bøhm 2008). Statistical data on the heat losses provided from the branch organizations and on the national level does not give a good indication how operation and temperature levels may contribute to the distribution losses. Different countries and DH companies register their historical and operational data in different ways. Usually, heat distribution losses as a function of linear heat density, as in Figure 5-4, may be found.

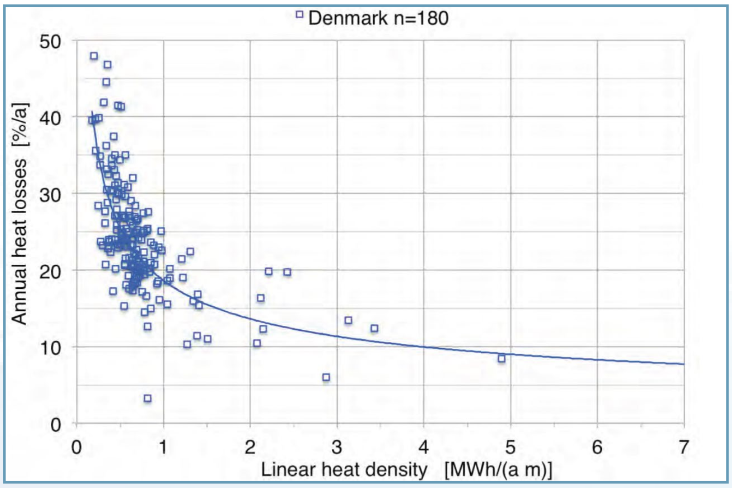

Figure 5-4 Heat distribution losses as function of the linear heat density in Denmark for plants (Verenum 2014)

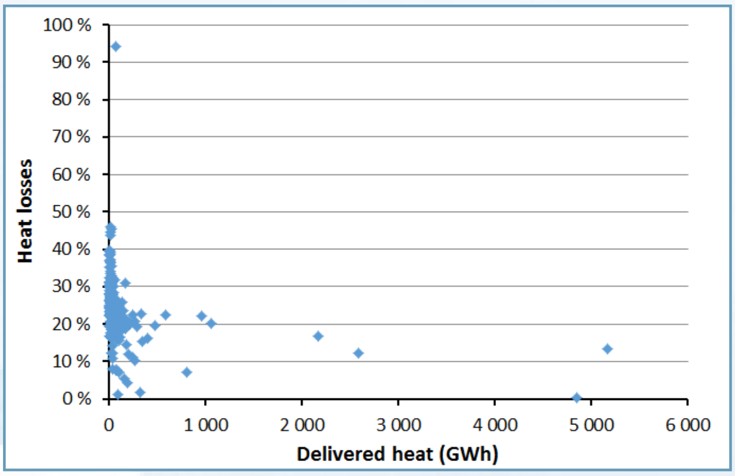

Figure 5-5 DH heat losses for separate plants in Denmark (Dansk Fjernvarme 2017)

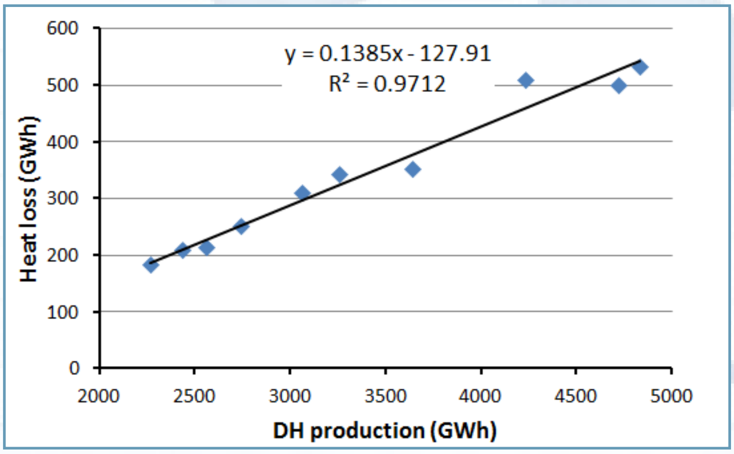

Figure 5-6 DH heat losses on national level in Norway (Statistics Norway 2017)

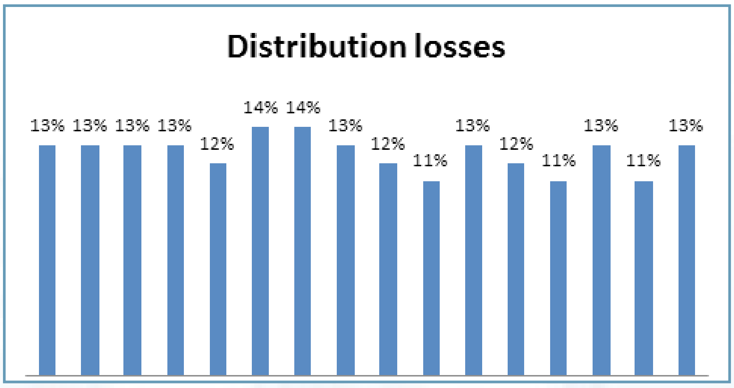

Figure 5-7 Percentage of DH distribution heat losses in Germany by years (AGFW 2014)

By using annual statistical data from Danish DH plants, it was possible to give relationship between the heat losses and delivered heat, as in Figure 5-5. It should be noted that varying pipe sizes, piping principles and pipe insulations applied in different networks are not considered in these data. On the contrary, in Norway it is not possible to find so detail data on distribution heat losses as in Denmark. The annual data on the national level may be found in Norway as shown in Figure 5-6. Similar data were found for Germany, see Figure 5-7.

Table 5-1 Summary and comparison of the characteristics for connection of local heat sources

Physical factors	Environmental factors	Operational factors
Pipe age and material	Pipe bedding	Internal pressure
Pipe wall thickness	Trench backfill	Leakage
Pipe vintage	Soil type	Water quality
Pipe diameter	Groundwater	Flow velocity
Type of joints	Climate	Backflow potential
Thrust restraint	Pipe location	Operational and maintenance practices
Pipe lining and coating	Disturbances	
Dissimilar metals	Stray electrical currents	
Pipe installation	Seismic activity	
Pipe manufacture		

As expected the general conclusions from the available data on the heat losses in the DH is that smaller DH plants and low linear heat density tend to have higher heat losses in percentage, see Figure 5-4 and Figure 5-5. Difficulties in collecting data on heat losses in the DH system may be noted in Figure 5-5. Someone may question some of the values in Figure 5-5, because some plant had heat loss of 94 %. However, such data points may be due to typing fail in the database or wrong calculation. This conclusion indicates that a better monitoring of the DH network and smart thermal grids are highly necessary for the LTDH and transition to the renewable society. A general overview on the German national heat losses indicated that the heat losses have been in the range of 13 to 14 %, see Figure 5-7. Regarding pipe reliability of the DH network, a thorough review identifies and classifies the most relevant factors leading to pipe deterioration as shown in Table 5-1 (Tereshchenko and Nord 2016). A good database should include well organized data shown in Table 5-1. Implementation of new IT-technologies should enable this.

5.3.2 Integration of renewable energy sources

To enable transition to the renewable energy society and secure energy supply for future development of society, integration of distributed energy systems is highly necessary. This will induce a new actor at the DH market called “prosumer” (Brange et al. 2016) that may be treated as third party access. A prosumer is a customer that both produces and consumes heat from the DH system. This concept offers great opportunities for successful utilization of solar heat into the DH and supports the transition to smart thermal grid. The concept of “prosumer” is already known from application in power sector (Schleicher-Tappeser 2012 and Menniti et al. 2013). In the DH context, this will imply that customers may have possibility to deliver excess heat from distributed renewable energies (e.g. solar heat, heat pumps, and waste heat) to the DH network. There are different approaches for the prosumer connections, depending on the DH network temperature level, delivered heat tempera-

ture level, and building requirements, see chapter 4.6 Prosumer may deliver their heat into the supply or return line. The concept of exporting excess heat from the cooling machines (CM) to the DH network is shown in Figure 5-8.
Under the case a) in Figure 5-8 it is assumed that the DH network and buildings need higher temperature and therefore a heat pump (HP) is necessary to increase the temperature of the prosumer heat to the required temperature level. In the case b) in Figure 5-8, the excess heat is directly exported to the DH grid, while buildings may have possibility to increasing the temperature level, by including an electric boiler for heating the tap water.
With increasing the number of prosumers in the DH system, a transformation of today's DH network into a smart thermal grid is highly necessary. The introduction of prosumers to the DH will affect both the DH network and the customers.
When prosumer are introduced into a DH scheme, network operators should consider lower DH temperatures because of:
1) lower temperature requirement for utilization of renewable and waste heat and
2) renewables produce heat with higher efficiency at lower temperature level. This can only be done taking the minimal temperature requirements of the connected buildings into account.
Heat production from the prosumers to the DH network will influence pressure levels in the DH network. When the prosumers produce at their maximum, the water velocity in the pipes will increase. Therefore, it is necessary to analyze pipe sizes before introducing prosumers and size the pipes for heat production instead of just heat use. Introduction of the prosumers will may cause a bidirectional flow in the DH pipe network as it is actually very common in DH systems with pooled heat sources. Further the prosumers may create own pressure cones resulting in high differential pressures for some of the consumers close to the prosumers. In general distributed heat sources / prosumers will reduce the overall pressure difference in the system. To enable higher heat share from the prosumers, it might be advantage to allow lower initial pressure difference from the main plant. The initial pressure at the plant is generally controlled according to the differential pressure at the critical user. However, this differential pressure requirement from the critical user should be considered. (Lennermo 2016 and Brand et al. 2014). Therefore, new control strategies for the differential pressures are highly important to enable proper operation of the whole DH system with the prosumers.

5.3.3 Successful examples of integration of excess heat

Nowadays datacentres need lots of cooling, while condensers of the cooling plants may provide heat for useful purpose. Integration of the excess heat may be done in the supply or in the return line of the DH system. Viborg DH in Denmark is an example where the surplus heat from a new Apple computer center will be rejected to the DH system (Diget 2015), see Figure 5-9. To provide heat for the DH system, heat pumps are imple-

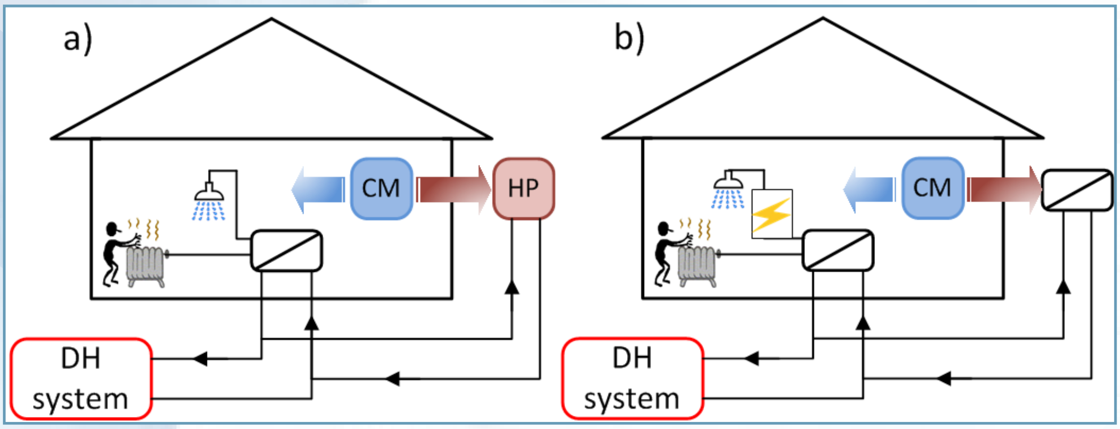

Figure 5-8 Examples of waste heat integration into DH – a) with heat pump for higher temperature level and b) low temperature DH network (Brange et al. 2016)

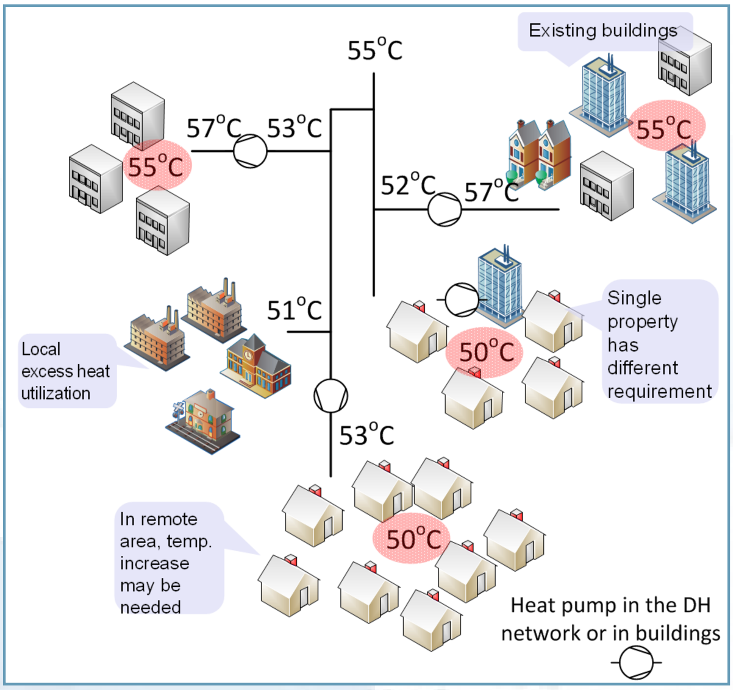

Figure 5-9 Example of waste heat based DH in Viborg in Denmark (Diget 2015)

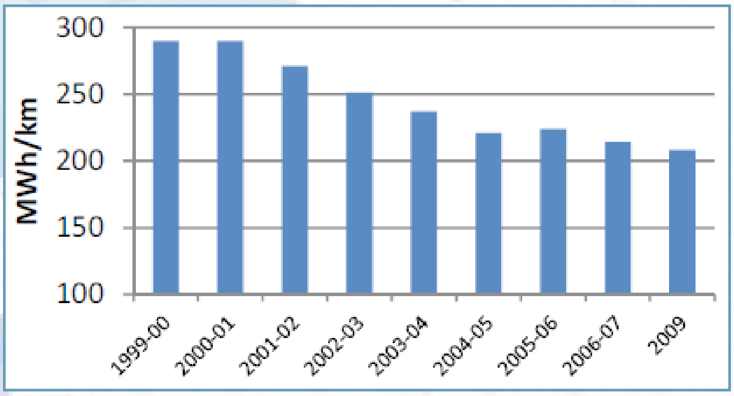

Figure 5-10 Planned decrease in the DH distribution heat losses in Viborg DH to enable utilization of excess heat from the datacenter (Viborg Fjernvarme 2011)

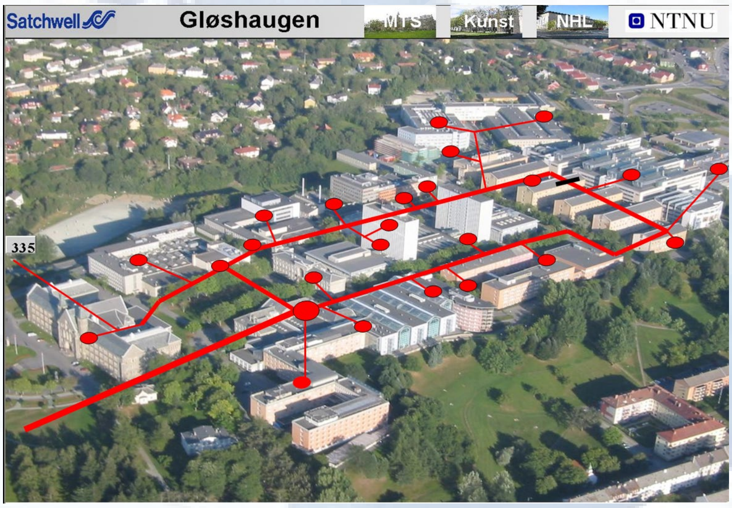

Figure 5-11 Use of excess heat at NTNU in Trondheim, Norway (NTNU Property owner 2012)

mented, thus providing directly supply water for the DH system of approximately 50 °C. Viborg DH-company had a long-term plan for decreasing the DH temperature and distribution losses, see Figure 5-10 (Diget 2015 and Viborg Fjernvarme 2011) This has been done based on considerations to optimize the network operation and because of realizing a better business case via reducing the temperature in the network. Opening of Apple data center fitted very well into the strategy of Viborg DH. Customers with the high temperature requirements will be grouped and provided with an additional heat pump for increasing the temperature level. In Trondheim, Norway, excess heat from cooling the datacenter at the university campus is utilized by connecting in the return line, see Figure 5-11. The reason for this was currently high temperature level requirement from the existing buildings at the campus. To enable integration of the excess heat, the university campus separated from the main connection to Trondheim DH by using heat exchangers and establishing own DH ring. In that way, it was possible to control the supply and return water temperature in the university DH ring and utilize excess heat from the datacenter. Proper control was enabled easily because university is property owner and has own maintenance service with a powerful building energy monitoring system for the entire campus. Currently, the excess heat may provide the base heat load in the range of 1 to 1.2 MW the entire year.

5.4 Optimization, interaction, and energy measurement

To enable low supply temperature in the DH system, it is highly important to decrease as much as possible the return temperature. Importance of the low return is pointed out in Section 5.3 for the purpose of integration of the renewables and excess heat. An approximate calculation shows that the economic value of reduced return temperature can vary from 0.05 to 0.5 EUR/MWh°C (Frederiksen and Werner 2013). A big problem in achieving low return temperature is poor substation control. Different faults induce problems with high return temperature in the consumer substations, see Figure 5-12. Control and set points are causing most of

the issues in achieving the low return temperature. Therefore, fault detection and diagnosis (FDD) of the consumer substations is highly important in achieving low return and consequently low supply temperature in the DH system.
Wireless and smart metering technologies may provide lots of data on the substation performance and the DH network. By transforming these data into information, it is possible to improve the overall system operation and optimize the overall system performance considering together DH companies and consumers. Better data utilization may create new business development and build new business models tying utilities, energy companies, and consumers tighter together. New business models may be relevant for the DH companies and new actors on the market. For the DH companies, this may imply that they can take over operation and maintenance of the consumer substations and operate them in the optimal way for the DH plant and costumers. In addition, new companies transforming data into useful information by using the newest IT-technologies and advanced control may be developed. An example for such company is NODA in Sweden. This company is dealing with big data applications for energy heating systems (Noda 2017).

5.5 Pricing and business models

District heating pricing is a core element in reforming the heating market, because the heat price and price for the heat export will influence decision on energy source and an active customer role. Existing DH pricing methods, such as the cost-plus pricing method and the conventional marginal-cost pricing method, cannot simultaneously provide both high efficiency and sufficient investment cost return (Zhang et al. 2013). The cost-plus pricing method is often used in regulated DH markets. The marginal-cost pricing method is commonly utilized in deregulated markets (Li et al. 2015).
Regarding excess and solar heat delivery to the DH system, several price and business models have been developed. In Denmark, DH operators are mostly organized in cooperatives. Their goal is not profit maximization, but to achieve a long-term favorable price

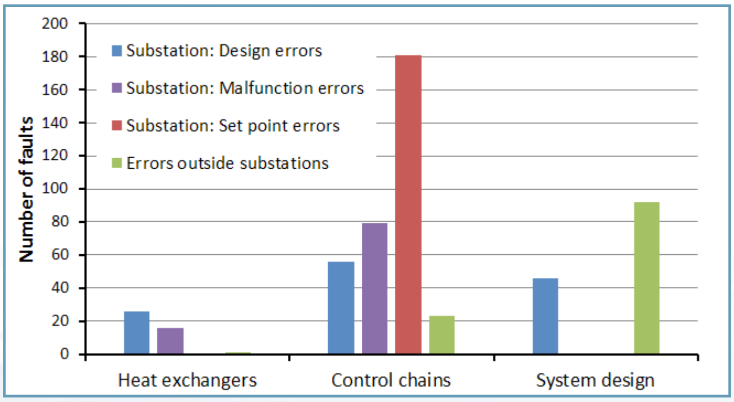

Figure 5-12 Amount of fails in the consumer substations (Frederiksen and Werner 2013)

using renewable energies for heating. An example of solar heating plant is in Marstal on island Aerö, Denmark. The 33,400 m² solar collectors combined with the 75,000 m³ thermal storage provide 55 % of the annual heat demand. The district heating company is citizen-owned. In Gothenburg, Sweden, owners of the DH connected buildings installed large solar collectors. In this case, the solar heat is first used in the buildings. When the solar heat production exceeds the heat demand of the building, it is exported to the main DH network. The DH network is kind of storage for the solar heat. In this example, where the building owners installed the solar collector, a problem with delivering less heat then expected has been noticed. In Austria, Energy Service Companies (ESCO) own and operate the solar heating system. This means that ESCO is the third party company (Dalenback 2015).
Based on the available data on the solar heat production, it seems that the price and business models in Denmark resulted in a very high share of the solar heat into the DH system. In addition, the Danish DH solar systems are rather big plants than many small plants. In this model where the solar heat plant is owned by the DH companies, proper operation is directly provided enabling desired temperature levels and operation.

6 CALCULATION TOOLS FOR DISTRICT HEATING SYSTEMS

6.1 Introduction

During the course of the work within Annex TS1 a methodology for assessing and analyzing procedures for the optimization of local energy systems with focus on DH has been identified and adapted. Furthermore, a simplified planning tool for DH is developed and advanced tools for design and performance analysis of local energy systems, which are based on DH, are further developed.
The presentation of tools in this chapter is part of the German contribution to the Annex and a summary of the full report (Blesl and Stehle 2017).
For the evaluation of existing local and DHC models, a classification form was created together with Annex TS1 participants to conduct a survey on planning tools for DH. The used classification categories are summarized in Table 6-1.
Input from Annex participants (in total twelve planning tools) could be gathered and evaluated to formulate requirements for the development of a simplified DH planning tool and to further develop an existing advanced tool (TIMES Local). Based on this, a new simplified planning for DH has been outlined and developed: Easy District Analysis (EDA). EDA is a simplified DH planning tool for urban planners for the energetic, ecological and economic analysis as well as the evaluation of urban districts.
In the following the results of the survey on local and DHC models are described and evaluated. The developed Easy District Analysis (EDA) tool is then presented and applied to a case study of an urban district consisting of 140 multi-family houses.

Table 6-1 Classification categories for the evaluation of planning tools for district heating

Analytical Approach	**Demand Categories**
Energy System Model	Households
Thermodynamic Model	Commercial
	Industry
Target Audience	Transportation
Municipal Authorities	
Professional Planners	**Final Energy Consumption**
Internal Use, R&D	Electricity
	Heat
Level of Detail	Transport
Geographical Scope	
Time Horizon	**Variables**
	Costs
Model Type	Energy
Simulation Model	Exergy
Optimization Model	Temperature

6.2 Description of Planning Tools for District Heating

Based on the survey results on local and DHC models, twelve planning tools for DH are briefly described in the following. As a first step, the analyzed planning tools are divided according to their analytical approach: energy system models, thermodynamic models and others (see Table 6-2).
Energy system models describe energy flows from primary energy over transformation, transport and distribution to final energy and useful energy. They are therefore suitable for an integral approach on low temperature DH. However, heat distribution and different temperature levels are often not modelled in energy system models in detail.
Thermodynamic models are therefore also included in the survey on local and DHC models in order to consider heat grids along with their hydraulic and thermodynamic characteristics as well as different supply temperature levels of renewable energies (e.g. solar thermal, geothermal, heat pumps) to feed into the heat grid.
Models that neither described an energy system nor thermodynamic characteristics were classified as **others**.

6.2.1 Energy System Models

In the following five energy system models are briefly presented (including two models that also contain thermodynamic aspects):
EnergyPLAN, KOPTI, TIMES Local, LowEx-CAT and SIMUL_E.Net.

Table 6-2 Overview of planning tools from the survey on local and DH models

Energy System Models		
EnergyPLAN	KOPTI	LowEx-CAT
SIMUL_E.NET	TIMES Local	
Termodynamic Models		
HeatNET	LowEx-CAT	NET Local
SIMUL_E.NET	spHeat	Termis
Others		
District ECA	EME Forecast	Exergy Pass Online

EnergyPLAN

EnergyPLAN, developed at Aalborg University in 2000, is a simulation and optimization model to run a regional to national future energy system in which the sectors power, heat and transport are linked via e.g. power to heat or e-mobility. To integrate intermittent renewable energy, the model is run in an hourly resolution with a time horizon of one year. The energy system (installed capacities, energy demand) needs to be set up by the user. The usage of technologies is optimized with the goal of minimum costs or minimum fuel use. An example for model application is a heating and cooling strategy for Europe in 2014 (Connolly 2014).

KOPTI

KOPTI (Kokonais OPTImointimalli, engl. overall optimization model) is an optimization model that was developed at VTT Technical Research Centre of Finland in 2003. It optimizes the run of a local energy system with the focus on the DHC system (e.g. CHP, storages) including the power system under the goal of minimum costs of electricity, heat and cooling. Market heat and electricity prices are considered in order to sell utilization options to the market (Koreneff 2014b). KOPTI has been applied to 'estimate the value of distributed generation for the different power system actors' (Koreneff 2014b).

TIMES Local

TIMES Local, based on the TIMES (which was developed within a working group of the Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency in the 1990s) model generator, is an optimization model, that was developed at the Institute of Energy Economics and Rational Energy Use (IER) at the University of Stuttgart in 2010. The focus lies on the heating market to optimize a local energy system with the target of minimizing the total system costs under defined constraints (e.g. CO_2-reduction). TIMES Local enables the energetic, ecological and economic analysis of the heat and power supply of a city taking into account the settlement and building structure of urban districts and its heat supply structure and alternatives. After the initial used technologies, the development of energy demand, energy prices, etc. are set, the model decides which technologies are used to achieve a cost minimum solution. The model's time horizon can be set up to several decades on an hourly basis. An example for model application is the German research project 'EnEff: Stadt Ludwigsburg-Grünbühl/Sonnenberg' in 2013 (Blesl 2014a). Further details on TIMES Local are presented in (Blesl and Stehle 2017).

LowEx-CAT

LowEx-CAT, Low Exergy – Cluster Analysis Tool, is a TRNSYS-based simulation model (Kallert 2017). The focus of the model is the integration of low temperature technologies (e.g. solar collectors, heat pumps) to supply districts by DH grids (considering grid temperature, design and optimization of the grid distribution). The time horizon ranges from season to less than five years on an hourly basis. After the design of the district energy system is set up, the operation of an energy system is optimized by minimizing the degradation of exergy (exergy efficiency). This enables the analysis of the energy and exergy impact of different energy strategies (Kallert and Schneider 2014). The model is applied to several generic case studies (e.g. Kallert 2017). Further descriptions of LowEx-CAT can be found in (Blesl and Stehle 2017).

SIMUL_E.NET

SIMUL_E.NET is a simulation model based on Simulink (MathWorks 2017) for new concepts of DHC grids. It focuses on bi-literal heat trade between consumers and suppliers or between prosumers in a small grid with several connected buildings. Although SIMUL_E.NET focuses on bi-lateral energy trades on the DHC network, it also considers supply technologies and is therefore also listed under energy system models. To realize these bi-lateral heat trades different variants of Energy Management System (EMS) algorithms are analyzed (Im 2014). Aside the grid and demand of buildings, supply and storage technologies are considered. Moreover, different pipe configurations or temperature levels can be taken into account to improve the efficiency of the grid. The model's time horizon is one year with an hourly resolution. References for model use do not exist so far.

6.2.2 Thermodynamic Models

In the following four heat grid models are described briefly:
HeatNET, NET Local, spHeat and Termis.

HeatNET

HeatNET, has been developed by the VTT Technical Research Centre of Finland since 2005, is a district heating network simulation model with a dynamic temperature calculation. Time step and length of a simulation can be defined by the user, the most common simulation being a period of one year with a time step of one hour. As input the user enters network related data (e.g. structure, pipe size, feed temperatures, and capacities) and defines the heat demand for heating and domestic hot water, as well as a set of consumer specific information such as e.g. heat exchanger parameters. The simulation of a district cooling network can also be performed by HeatNET. The model determines flows, heat losses and temperatures and pressures around the network (Rämä 2014). The model was applied for network calculation(s) in Finnish DH-systems, e.g. Hyvinkää building exhibition area case, see chapter 7.2.1. and (Rämä 2014).

NET Local

NET Local is a static temperature simulation model for DHC grids that has been developed since 2012. It analyzes the influence of heat demand on different temperature levels of representative buildings or consumers on the grid temperature and possible supply types. This involves the evaluation of return line supply. Moreover, the temperature change along the district heating grid with a regional resolution is taken into consideration. The impact of different technology options, such as solar heat integration, can also be considered. The calculation is carried out for one single demand point with the output of the DHC grid temperature for feed line and return line in different supply regions. Model results are used to verify optimization results of TIMES Local (see 6.2.1). Examples of model application are 'Ludwigsburg Grünbühl'/Germany and 'Stuttgart West'/Germany (Blesl 2014b).

spHeat

spHeat is a quasi-dynamic heat grid model that was developed in 2012. It performs a 'hydraulic and thermal simulation of networks with multiple loop topologies' focusing 'on the impact of the spatial/geographic load distribution on the performance of the network' (Hassine 2014). The time horizon ranges from single design point to one year on an hourly basis. The model's outputs are pressure and temperature profiles along the grid. Aside structural improvement potentials spHeat can 'analyze different solar thermal energy supply strategies' (Hassine 2014). spHeat was used for case studies such as 'Scharnhauser Park Ostfildern' and 'Sonnenberg Ludwigsburg', both in Germany. More details on spHeat can be found in (Blesl and Stehle 2017).

Termis

Termis is a heat grid model that was developed by Schneider Electric (Schneider Electric 2014) in 1988. It is able to perform both simulation and optimization of heat grids both in planning and operation stage. However, heat generation technologies such as CHP are not considered. The time horizon ranges from single design point to one year with a time resolution from 10 to 60 minutes or one year with twelve typical discrete loads. Termis does also use real-time data (SCADA) to optimize grid parameters. The model output is among other things the 'process state of the network and network components' (i.e. power, pressure, flow, temperature) (Outgaard 2014). Termis is not only used by e.g. Danish consulting companies for design analysis or real time operation and optimization, but also for projects in France, Spain, USA, Poland, Serbia, China, etc.

6.2.3 Others

Aside from energy system and thermodynamic models, other analytical approaches were considered in the following three models: Firstly, District ECA is described as a district energy concept tool for the assessment of the energy potential and efficiency. Secondly, a heuristic time series model to forecast heat and electricity loads is regarded: EME Forecast. Finally, a tool for the exergy analysis of the resource consumption of buildings: Exergy Pass Online.

District ECA

District Energy Concept Adviser is a static and myopic simulation model that was developed as part of the German EnEff:Stadt research activity in 2012 (Fraunhofer IBP 2014, ANNEX 51 2014). It is used by urban planners during the first stage of district concepts. After the specification of the buildings and the energy supply, the final energy consumption and CO_2 emissions are calculated. This allows comparing different energy concepts such as local district heating or the use of gas condensing boilers. The regarded time horizon is one year with the same time resolution. Moreover, District ECA enables comparisons in energy use of a district with the national average and provides examples for energy efficient districts. Examples for model applications can be found in the German programme 'EnEff: Stadt', e.g. Stuttgart-Burgholzhof, Munich-Lilienstraße, Karlsruhe-Rintheim (Fraunhofer IBP 2014).

EME Forecast

Developed in 2002, EME Forecast is a heuristic time series model to forecast electricity and heat loads on an hourly basis. The time horizon can be adapted from single design point to ten years. It is used by VTT and a Finnish power supplier. The approach is to assume that a behavior of a variable in future (e.g. DH load) can be derived from historic data. Therefore, the model needs both history and forecast values of a variable that the DH load is dependent of (such as the outside temperature) and history values of the DH load itself. The forecasted hourly DH load is received by performing a heuristic time series approach combined with a dynamic regression analysis (Koreneff 2014a). A reference for model use is the end-user load forecasts by Koreneff in 2010.

Exergy Pass Online

Exergy Pass Online, developed from 2012-2015, is a tool for the exergy-based assessment of the resource consumption of buildings.
The model enables the comparison of buildings 'to find the optimal combination of heating, cooling, insulation standard and electrical appliances' in order to reduce resource consumption and GHG emissions (Jentsch 2015). After specification of the building's energy demand and selection of the supply technologies, the model's output is a predefined result report (exergy pass) on resource consumption (exergy), energy, GHG emissions and costs. In contrast to energy passes, the exergy pass takes energy quality (Energy quality can be described as the usefulness of energy. Its unit is the maximum share of energy that can be converted into electricity (Exergieausweis 2015)) into consideration and uses exergy as an assessment parameter for the evaluation of energy systems in the building sector. The exergy pass (only a German version available) will be used in the EU project SUSMILK (Jentsch 2015).

6.3 Evaluation of Planning Tools for District Heating

Based on the descriptions of local and DHC models in the last section, an evaluation of them is carried out to identify integral and innovative approaches for low temperature heat supply at local level. This chapter concludes with the requirements for the development of a simplified tool for DH, which is presented in next chapter.

6.3.1 Methodology

To evaluate the survey results on local and DHC models, the gathered input is filtered and classified in seven categories (and some in subcategories):

- analytical approach,
- target audience,
- level of detail (geographical scope, time horizon),
- model type (simulation, optimization),
- demand sectors,
- final energy consumption and
- solution variables.

Each of these categories includes distinguishing features which apply (green box), partly apply (yellow box) or do not apply (grey box) to the analyzed model (see Table 6-3).

The category analytical approach distinguishes between **energy system model**, **thermodynamic model** and **other**. Target audience includes **municipal authorities**, **professional planners and research & development / internal use**. The level of detail is split into the subcategories geographical scope (from **DHC supplied area** to **region**) and time horizon (**single design point, <= 1 year, > 1 year**). The model type is classified in **simulation**, **investment/design optimization** and **operation optimization**. Whereas demand sectors were divided into **households**, **commercial**, **industry and transportation**, final energy consumption was allocated to **electricity**, **heat** and **transport**. As solution variables **costs**, **energy**, **exergy** and **temperature** were used.

6.3.2 Evaluation and Comparison of Planning Tools for District Heating

The classification results of the twelve analyzed planning tools are summarized in Table 6-3. Each tool is assessed in the above-named seven categories (e.g. analytical approach), whereby green boxes in Table 6-3 mean 'true', yellow boxes 'partly true' and grey boxes 'false'. For example, District ECA is suitable for the target audience of municipal authorities. In contrast, boxes in grey mean that a model is not suitable, e.g. TIMES Local does not address to municipal authorities.

The classification results, as shown in Table 6-3 can also be used for a more accurate application of the planning tools for DH. In the following each category is evaluated with regard to the analyzed planning tools.

Analytical Approach

The analytical approach differentiates between energy system models, thermodynamic models and other models. Energy system models cover the energy supply chain from primary energy to useful energy, whereas thermodynamic models focus on heat networks. Models that did not fit in this classification were classified as others. As energy system models were classified: EnergyPLAN, KOPTI, TIMES Local, LowEx-CAT and SIMUL_E.NET. The latter two can also be described as thermodynamic models. Thermodynamic only models are HeatNET, NET Local, spHeat and Termis. Classified as other were District ECA, EME Forecast and Exergy Pass Online.

Target Audience

The target audience can be divided into municipal authorities, professional planners and internal use, R&D. The following models address among others municipal authorities and can thus be described as rather user-friendly tools: EnergyPLAN, Termis, District ECA, EME Forecast, Exergy Pass Online. Anyway, most tools require at least trained users, especially tools used by researchers or professional planners.

Table 6-3 Evaluation of twelve planning tools on the basis of classification categories (green = true, yellow = partly true, grey = false).

Classification Categories			Energy PLAN	KOPTI	TIMES Local	LowEx-CAT	SIMUL_E.NET	Heat NET	NET Local	spHeat	Termis	District ECA	EME Forecast	Exergy Pass Online
Analytical Approach	Energy System Model		✓	✓	✓	✓	✓							
	Thermodynamic Model					✓	✓	✓	✓	✓	✓			
	Other											✓	✓	✓
Target Audience	Municipal Authorities		✓								✓	✓	✓	✓
	Professional Planners		✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
	Internal Use, R & D		✓		✓	✓	✓	✓	✓	✓				
Level of Detail	Geographical Scope	Region	✓	✓	✓		✓	✓			✓		✓	
		City		✓	✓			✓			✓		✓	
		District		✓	✓	✓	✓	✓			✓	✓	✓	✓
		Street			✓		✓				✓		✓	✓
		DHC Supplied Area		✓	✓	(✓)		✓	✓	✓	✓	✓	✓	✓
	Time Horizon	Single Design Point		✓					✓	✓	✓		✓	✓
		<= 1 Year	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	
		> 1 Year			✓	✓					✓		✓	
Model Type	Simulation Model		✓	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Optimization Model	Investment/Design			✓						✓			
		Operation	✓	✓	(✓)	✓					✓			
Demand Categories	Households		✓	(✓) DHC, Electr.	✓	✓	✓	(✓) DHC Sector	✓	✓	✓	✓	✓	✓
	Commercial		✓		✓		✓		✓	✓	✓	✓	✓	✓
	Industry		✓								✓	✓		
	Transportation		✓											
Final Energy Consumption	Electricity		✓	✓	(✓)	(✓)	✓					✓	✓	✓
	Heat		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Transport		✓											
Variables	Costs		✓	✓	✓		✓				✓			✓
	Energy		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Exergy					✓								✓
	Temperature					✓		✓	✓	✓	✓			

Level of Detail: Geographical Scope

The geographical scope ranges from DHC supplied area, street, district, city to a whole region. Some tools are flexible in the geographic scope (e.g. TIMES Local, Termis, EME Forecast). Basically, most tools can cover a city level or parts of it (aside from EnergyPLAN that only models region and bigger). A DHC supplied area can be taken into account by most of the tools: the energy system models KOPTI and TIMES Local and the thermodynamic models HeatNET, NET Local, spHeat, Termis, as well as District ECA, EME Forecast and Exergy Pass Online.

Level of Detail: Time Horizon

For the time horizon a distinction is made between single design point (no time horizon), ≤ 1 year, > 1 year. A time horizon of up to one year can be modelled by any of the analyzed planning tools (except for NET Local). Longer time horizons are covered in TIMES Local (few decades), LowEx-CAT (less than five years), Termis (more than ten years) and EME Forecast (up to ten years). A few tools model all three categories of time horizon: Termis and EME Forecast. Both NET Local and Exergy Pass Online consider a single design point.

Model Type

The models were classified in simulation and optimization, whereas optimization is further divided into investment/design optimization and operation optimization. Simulation is part of any of the selected planning tools. Even though TIMES Local is primarily an optimization tool, it can also perform simulations if there are no degrees of freedom (such as investment decisions). However, optimization is only performed by some of the considered tools. Investment/design optimization is both modelled in the energy system model TIMES Local and in the heat grid model Termis. Operation optimization is performed by EnergyPLAN, KOPTI, LowEx-CAT and Termis. To some degree TIMES Local also optimizes the operation of an energy system, as the operational planning is optimized within investment/design optimization.

Demand Categories

The demand categories comprise households, commercial, industry and transportation. The analyzed planning tools focus mainly on two demand categories: Households and commercial. Industry is only taken into account by EnergyPLAN, Termis and District ECA (with some limitations KOPTI and HeatNET that do cover the DHC sector, not further specifying if industry is included). Transportation plays a minor role, as it is only included in one of twelve planning tools (EnergyPLAN).

Final Energy Consumption

Final energy consumption is divided into electricity, heat and transport. As planning tools for district heating are assessed, any of the investigated tools focuses on respectively includes the heat sector. Electricity is considered to some degree in any of the selected energy system models (e.g. although LowEx-CAT considers electricity using back-up heaters for DHW preparation, electricity generation is not taken into account). The transport sector is of minor importance for district heating and thus only considered in one tool (EnergyPLAN).

Variables

The analyzed solution variables are costs, energy, exergy and temperature. If they are sorted by their frequency, the following ranking results: energy (almost in all of the tools), costs (half of the tools), temperature (five) and exergy (only in two). This ranking indicates the relevance of the particular variable for local and DHC modelers. If grid models are not considered, it shows that different temperature levels (e.g. low temperature DH) are rarely modelled yet in system analytical approaches (apart from LowEx-CAT).

Overall evaluation

The evaluation of the analyzed local and DHC planning tools has shown some promising approaches for low temperature DH. For example, LowEx-CAT combines an energy system approach with a heat network approach to display exergy efficiency. However, technology detail is limited to five technologies.
To conclude, there was no planning tool found to be appropriate for the objective of a simplified, integrated tool for low temperature DH to enable analyses and comparisons of different heat supply options in terms of energy, ecology and costs. Based on the evaluation results, a simplified planning tool for DH is developed and presented in chapter 6.5.
Further evaluation results of existing local and DHC models can be found in (Blesl and Stehle 2017).

6.4 Summarizing Evaluation of DH Planning Tools

For the identification of integral and innovative approaches to low temperature heat supply at municipal level, an overview of existing approaches is provided here.
Initially, a classification form for local and DHC models was developed and distributed to tool developers. After obtaining the completed classification forms from the

Annex TS1 participants, the planning tools were assessed in seven categories: analytical approach (energy system model, thermodynamic model, other), target group of users (municipal authorities, professional planners, R&D), level of detail (geographical scope, time horizon), model type (simulation, optimization), demand categories (households, commercial, industry, transportation), final energy consumption (electricity, heat, transport) and used variables (costs, energy, exergy, temperature).

The planning tools were divided according to their analytical approach into energy system and thermodynamic models. Energy system models cover the whole energy supply chain from primary energy sources to useful energy. However, they usually do not consider the thermodynamics of district heating (e.g. interactions on thermodynamic level of processes with requirements of predefined temperature levels). Thermodynamic models are thus required. There are also planning tools that did not fit into the categories stated above. These were classified as 'others' (e.g. EME Forecast).

For the target group of municipal authorities planning tools, such as District ECA and Exergy Pass Online, come into consideration, as they are described as user-friendly and do not require trained users, unlike most other tools do.

Regarding the geographical scale, it is not only important at which level of detail a planning tool can be applied for, but also to know its range of scales. From the analyzed tools three tools can model all different scales from a whole region over city, district and street (neighborhood) to a DHC supplied area (e.g. TIMES Local, Termis, EME Forecast). Apart from streets, this also accounts for KOPTI and HeatNET.

Another aspects of detail are the modelled time horizon and the time resolution. Most of the considered tools cover a time horizon of one year and less with an hourly resolution. Longer time horizons are modeled in TIMES Local (few decades), LowEx-CAT (less than five years), Termis (more than ten years) and EME Forecast (up to ten years).

Simulation is part of any of the selected planning tools. However, optimization is only performed by five tools: EnergyPLAN, KOPTI, LowEx-CAT (all three operation optimization of an energy system); TIMES Local (investment/design optimization of an energy system); and Termis (operation and investment/design optimization of a heat grid).

As for the demand categories the focus lies on households and commercial buildings. Only some tools include the industry sector (EnergyPLAN, Termis and District ECA) and only one does the transportation sector (EnergyPLAN).

For an integrated approach of DH energy systems including CHP, the heat and power sector need to be considered. However, as planning tools for DH focus on the heat sector, the power sector plays a minor role or is not modeled at all. Transportation is usually not considered.

Even though costs are the essential variable to assess investments (e.g. into new or existing grids), an economic approach is only applied by about half of the selected planning tools for DH: EnergyPLAN, KOPTI, TIMES Local, SIMUL_E.NET, Exergy Pass Online, (meanwhile LowEx-CAT) and Termis as the only grid model.

The integration of renewable energy sources into the energy system is another important aspect of low temperature DH. Both EnergyPLAN and LowEx-CAT focus on this aspect. However, EnergyPLAN does not consider heat grids or urban districts - in contrast to LowEx-CAT.

For the evaluation of low temperature DH, the variable temperature is needed. Apart from the heat grid models only LowEx-CAT is able to include the temperature in simulations. LowEx-CAT, classified as both an energy system and thermodynamic model, seems to be a suitable tool for the evaluation of low temperature DH. However, the level of detail is limited to five technologies and costs were not taken into account (at the time of the evaluation, but are meanwhile considered).

The building stock as well as the development of urban districts is not considered by most of the selected planning tools. A promising approach is followed by District ECA, as it includes buildings along with their characteristics and energy demand as well as the supply at a district level. However, performing future scenarios is not possible, as well as modeling heat grids or entire energy systems.

To conclude, the evaluation has shown some promising approaches for low temperature DH. However, there was none found to be appropriate for the objective of a simplified, holistic tool for low-ex DH.

By evaluating the selected planning tools for DH schemes, requirements can be derived for the development of a simplified planning tool.

A simplified tool should be simplified in terms of user-friendliness, but not mandatory in the complexity of calculation. Due to the intermittent availability of solar energy, the analysis and evaluation of solar integration into heating grids along with thermal storage requires a high temporal resolution to cover the use of DH technologies. Aside the technical consideration, also economic conditions need to be covered by a simplified tool in high temporal resolution. For example, revenues for cogeneration from electricity feed vary due to hourly changing electricity prices. Thus, for economic optimization algorithms have to be developed to find the optimal use of technologies depending on economic conditions. Aside the comparison of technical and economic operation of DH systems, different temperature levels of standard and low temperature DH need to be analyzed with regard to the impact on carbon emissions and costs.

All in all, the simplified tool should enable the analysis and evaluation of different DH supply variants (e.g. solar integration), temperatures (standard DH vs. low temperature), operation modes (technical vs. economic operation) on the use of technologies and the related impact on carbon emissions and costs. Such a simplified planning tool is presented in the next section.

6.5 Easy District Analysis (EDA) – A Simplified Tool

The EDA tool (Easy District Analysis) is an excel-based simulation tool that has been developed by the IER (Institute of Energy Economics and Rational Use of Energy) at the University of Stuttgart (Germany) in cooperation with Annex TS 1 participants. It enables the easy analysis of districts in terms of energy consumption, CO_2 emissions and costs of different DH supply options.

The development of the simplified tool EDA involved several steps. Starting with an evaluation of existing planning tools for district heating to derive requirements for a simplified tool (see chapter 6.3), the methodical approach for the EDA-Tool was developed, implemented into Excel VBA, and applied to a case study.

6.5.1 Description and Methodical Approach

Easy District Analysis (EDA) is a simplified tool for urban planners and utilities for the energetic, ecological and economic analysis as well as the evaluation of districts with regard to low temperature heating to enable comparisons with other heat supply options.

EDA is a simplified tool rather in terms of the required amount of input data than in terms of the complexity of calculation. This means with little information on a district energy system that is being analyzed, an annual load profile is generated in hourly resolution (taking simultaneity of demand into account) to enable the integration of intermittent renewable energy (e.g. solar thermal) into the district heating system and to consider storage options. As a simplified tool EDA addresses mainly to urban planners, it is intended to be used in the pre-planning phase of a district energy system. The approach of EDA for the analysis and evaluation of energy supply options for districts is sketched in Figure 6-2 . Basically, the tool covers the urban energy system from supply side (energy carriers, technologies) over distribution (heat grid) to demand side (annual demand). As input the user selects supply technologies (e.g. CHP plus peak boiler) and energy carriers (e.g. natural gas), grid parameters (e.g. supply and return temperature) as well as the considered district (e.g. 100 multi-family houses). EDA calculates then a load

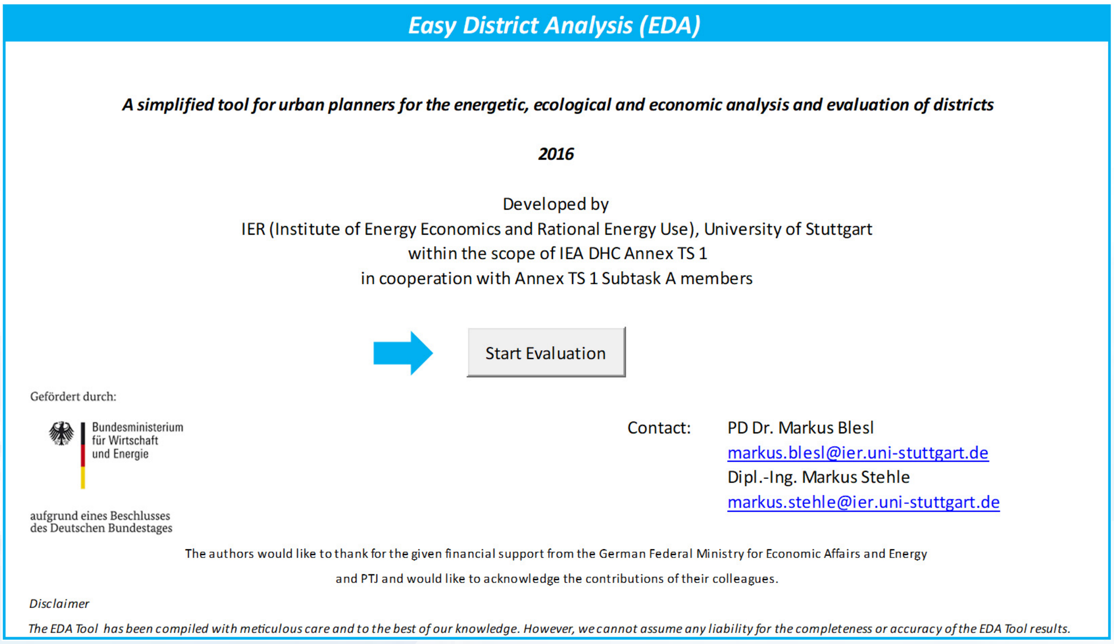

Figure 6-1 Start tab of the Excel VBA –based tool Easy District Analysis (EDA)

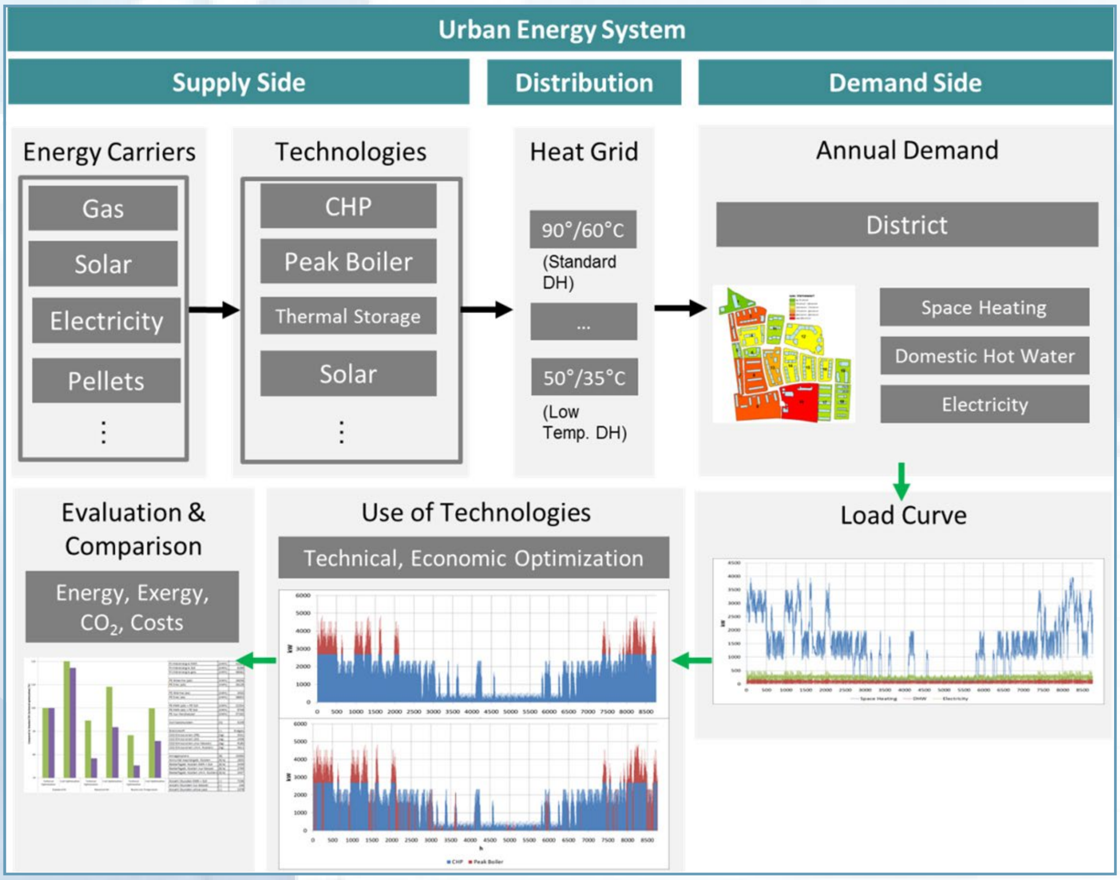

Figure 6-2 Approach for a simplified tool to evaluate energy supply options for districts: Easy District Analysis (EDA)

profile (space heat, domestic hot water), optimizes the use of technologies in technical or economic terms and enables the evaluation and comparison of different district heat supply options in terms of primary energy, final energy, CO_2 emissions and costs.

The structure of the EDA tool can be divided into input that follows the DH supply chain (supply, distribution, demand) and into output as the tool results (load curve, use of technologies, evaluation & comparison) (see Figure 6-2).

Supply
Four different DH supply options can be compared. The basic option is a DH system of cogeneration with boiler. These technologies can be compared for technical and economic operation. Furthermore, this basic DH system can be complemented by DH storage to decouple heat demand temporally from the supply side and to enable the use of cogeneration depending on electricity prices. To decarbonize DH supply, solar integration with thermal storage can be taken into account, whereby solar thermal energy is supplied by a ground-mounted solar collector field. The supply tasks of technologies in EDA include both space heat and domestic hot water (DHW).
For all technologies technical (e.g. efficiency), economic (e.g. fuel price, specific costs per kW) and ecological (e.g. CO_2 emissions) parameters can be set. The design of the CHP plant is calculated on preset full load hours or on the share of CHP heat on DH supply, and on the load profile of the present district.

Distribution
For the distribution of the supplied heat, different temperature levels for the supply and return line can be chosen, e.g. from standard DH (90 °C/60 °C) to low temperature DH (50 °C/35 °C), to analyze the impacts on resource consumption and CO_2 emissions. The efficiency of supply technologies is dependent on the chosen supply and return temperature.

Demand
Space heat and domestic hot water (DHW) are taken into account for the analysis of district heating supply. The calculation of space heat demand is based on the number and net floor area of different building types (single-family, multi-family houses, non-residential buildings) and associated specific space heat demands per m² which can be differentiated according to construction years. DHW demand is estimated by number of inhabitants or number of residential units and specific DHW demands per person/unit. There is no distinction for different temperature level requirements of DHW and space heat. Technologies on the consumer side (e.g. thermal storage inside buildings) are not part of EDA. However, different technologies of heat transfer on the demand side, such as low temperature radiators, can be considered by different efficiencies of the heat distribution inside the buildings. After the inputs are set, the EDA tool provides mainly three outputs: annual load curve in hourly resolution, the optimized use of technologies, and the evaluation and comparison of different district heat supply variants.

Load Curve
Based on the annual demand data, a load curve in hourly resolution is generated. As demand of multiple consumers shows a certain degree of simultaneity, a shift algorithm based on a Gaussian distribution was developed to consider equalizing effects on the load profile (see more on load profiles in chapter 6.5.2).

Use of Technologies
Based on the generated load profile and set input parameters (e.g. full load hours), the design of the cogeneration plant with boiler is calculated. The design of other technologies, such as a ground-mounted solar collector field and respectively or district heating storage, can be preset or based on design criteria (e.g. solar fraction or m³, kWh). The DH storage can be used as short-term storage (e.g. daily storage of CHP heat to profit from high electricity prices at the EPEX SPOT (European Power Exchange for power spot trading)) or long-term storage (e.g. seasonal storage of solar energy) depending on the design of the storage.
The use of these technology capacities can be optimized technically and economically. Technical optimization means minimizing primary energy consumption by maximizing the use of efficient technologies such as CHP. Economic optimization means to run a heat supply system in a cost minimal mode by considering the revenues from CHP electricity, which depend on changing electricity prices.

Evaluation & Comparison
Different DH supply technologies (e.g. CHP with peak boiler) and operation mo-

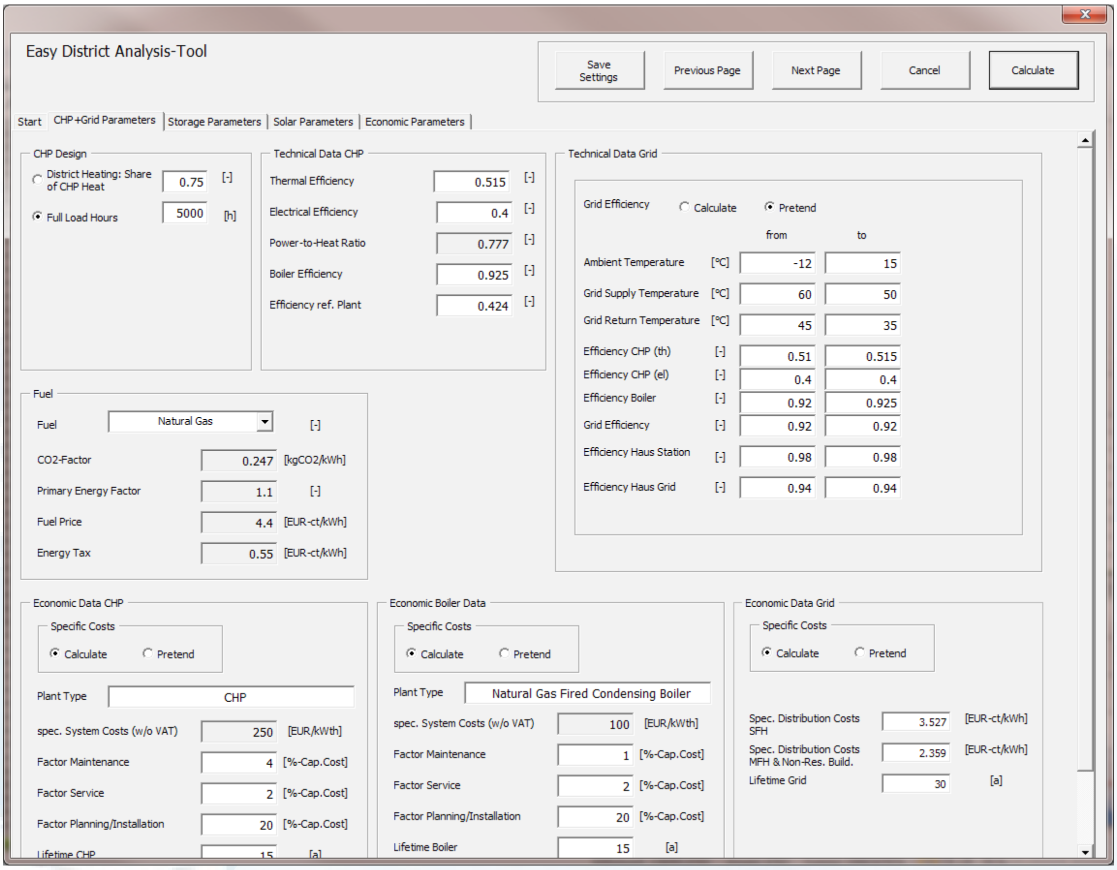

Figure 6-3 Input parameters for CHP plant, boiler and the grid can be set in the EDA-Tool

des (technical operation, economic operation) for a given demand can be evaluated and compared in terms of the use of technologies and related primary energy consumption, carbon emissions and costs. As technology parameters can be set by the user both an existing and new DH system can be evaluated.

The EDA tool enables the analysis of four different supply options:

1. Technical operation of cogeneration with boiler (TechOp)
2. Economic operation of cogeneration with boiler (EconOp)
3. Economic operation complemented by DH storage (EconOp+Storage)
4. Economic operation with solar integration and DH storage (EconOp+Storage+Solar)

Technical operation (1) and economic operation (2-4) differ in the goal of optimizing the use of technologies: Whereas technical operation involves minimizing primary energy consumption by maximizing the use of efficient technologies (e.g. cogeneration), economic operation means to operate the technologies at marginal costs (which depend on e.g. the revenues from CHP electricity feed). As a result technical operation leads to minimal carbon emissions and economic operation to minimal operation costs. In case of economic operation (4) of solar DH with storage, solar energy is given priority over cogeneration, although marginal costs of cogeneration might sometimes be lower (e.g. during high electricity prices).

Aside the evaluation and comparison of different DH supply options and operation modes in terms of primary energy consumption, carbon emissions or heat production costs, the effect of solar integration on the use of DH technologies (e.g. cogeneration, boiler) can also be assessed.

6.5.2 Load Profile Generator

The methodical approach for the generation of load profiles differs for residential and non-residential buildings. In the following the generation of load profile for residential buildings is described (for the description of load profiles for non-residential buildings see (Blesl and Stehle 2017).

Residential Buildings

The EDA tool distinguishes between two types of residential buildings: single-family and multi-family houses. As energy demand of buildings fluctuates depending on the season of a year (summer, winter, transition), weather (sunny, cloudy) and consumer pattern (workdays, Sundays) ten different typical days are defined as shown in Table 6-4.
Typical days represent typical load profiles of space heat, domestic hot water and electricity demand of single-family and multi-family houses, whereby 15 climate zones in Germany are differentiated. The energy demand (space heat, domestic hot water, electricity) of a typical day is basically calculated with the annual demand and with an energy demand factor for the typical day, which is given by the VDI guideline 4655 (VDI 4655 2008) for the different buildings types and climate zones in Germany. For domestic hot water and electricity demand the number of persons (for single-family houses) or the number of flats (for multi-family houses) is also taken into account (see formulas (6-1) - (6-3)):

$$Q_{Heat,Typical\ Day} = Q_{Heat,a} * F_{Heat,Typical\ Day} \tag{6-1}$$

$$Q_{DHW,Typical\ Day} = Q_{DHW,a}(\frac{1}{365} + N_{Pers\ /\ Flat} * F_{DHW,Typical\ Day}) \tag{6-2}$$

$$W_{Electr,Typical\ Day} = W_{Electr,a}(\frac{1}{365} + N_{Pers\ /\ Flat} * F_{Electricity,Typical\ Day}) \tag{6-3}$$

with

Q_{Heat}: Space heating demand [kWh]
Q_{TWW}: Domestic hot water demand [kWh]
W_{Electr}: Electricity demand [kWh]
$F_{Typical\ Day}$: Energy demand factor of a typical day [-]
N_{Pers}: Number of persons (single-family house)
N_{Flat}: Number of flats (multi-family house)

To arrange these typical days chronologically within a year, weather data on cloud coverage and ambient temperature are used from test reference years (TRY) provided by the German Weather Service (DWD). An hourly resolution is obtained when the demand of a typical day is multiplied by a normalized hourly value, which is given by the VDI guideline 4655 depending on climate region and building type.
By means of this information an annual load profile is generated in an hourly reso-

Table 6-4 Classification of typical days (according to VDI 4655)

Season	Workday [W] (based on calendar)		Sunday [S] (based on calendar)	
	Fine [H] (Average cloud amount <5/8)	Cloudy [B] Average cloud amount >=5/8)	Fine [H] (Average cloud amount <5/8)	Cloudy [B] (Average cloud amount >=5/8)
Summer [S] $T_{average}$ >15 °C)	SWX		SSX	
Transition [Ü] $T_{average}$ =5 °C...16 °C	ÜWH	ÜWB	ÜSH	ÜSB
Winter [W] ($T_{average}$ <5 °C)	WWH	WWB	WSH	WSB

lution for one building. As demand of multiple consumers does not happen in simultaneity, load profiles cannot be simply added up. Simultaneity factors that consider the simultaneity of demand for space heat, domestic hot water and electricity are therefore considered.

$$gf = \frac{\sum P(t_{max})}{\sum P_C} \qquad with\ gf = [0 \dots 1] \tag{6-4}$$

with

gf: Simultaneity Factor

$P(t_{max})$: Maximum requested performance within a year

P_C: Performance, if all consumers would demand the maximum performance simultaneously

As simultaneity factors relate on the maximum requested performance [kW] within a year (see formula (6-4)), they provide no detail on the hourly distribution of demand [kWh] of multiple consumers. Therefore, a shift algorithm was developed to consider equalizing effects on the load profile (see formula (6-5)). Based on a Gaussian probability distribution, the demand of one hour is shifted to other hours (from minus twelve to plus twelve) assuming that a shift of few hours is more likely than a shift of several hours. The variance of the Gaussian distribution was derived from the simultaneity factor, depending on the number and kind of consumers. The shift algorithm can be seen in formula (6-5), whereby gf_h is a weighting factor for the load shift from minus twelve to plus twelve hours (see formula (6-5).

$$Load_{h,shift} = \sum_{h=-12}^{h=-1} Load_h * gf_{h+24} + \sum_{h=0}^{h=12} Load_h * gf_h \tag{6-5}$$

The weighting factor gf_h can be described as follows:

$$gf_h = \frac{N_{SFH,MFH,NRB}}{\sqrt{2\pi * \sigma^2}} * e^{-\frac{h^2}{2\sigma^2}} \tag{6-6}$$

with

$N_{SFH,MFH,NRB}$: Number of single-family houses, multi-family houses, non-residential buildings

h: Shift in hours

σ^2: Variance

As a result an annual load profile for different kinds of demands and buildings is generated in hourly resolution taking simultaneity of demand of multiple consumers into account.

6.5.3 Optimization of the Use of Heat Supply Technologies

The optimization of the operation of different DH technologies can be performed by the EDA tool in two ways: technical and economic optimization.

Technical operation means to maximize the use of efficient technologies (such as cogeneration) in order to minimize primary energy consumption, although this might involve higher operation costs.

Economic optimization leads to cost-minimal operation of DH technologies, although this might involve higher primary energy consumption and greenhouse gas emissions. The hourly cost-effective mode of operation depends on fuel costs (that are assumed to remain unchanged within a year), varying efficiencies (dependent on supply temperature levels) and varying revenues from power production. For example, in Germany according to the combined heat and power law 2016 (KWKG 2016) electricity fed into the grid produced by CHP plants greater than 100 kW_{el} need to be traded directly (e.g. on the power exchange EPEX SPOT (European Power Exchange for power spot trading)). Therefore, operation costs of cogeneration depend on the varying electricity prices. Moreover, cogeneration electricity receives financial support, unless the electricity prices are negative. For negative electricity prices (e.g. during periods of high renewable power generation), the operation of a CHP unit can become less economic than the single operation of a boiler (see Figure 6-4). This might be more often the case in the future, as negative electricity prices at the European Power Exchange (EPEX) are expected to become more frequent.

A flow chart in Figure 6-5 describes the decisions that the EDA tool has to undergo in order to identify the cost minimum operation of a DH system (CHP and boiler). Three decisions are made along the program sequence: Electricity price negative or not (green), heat load higher than thermal output of the CHP unit or not (blue) and costs of CHP and peak boiler greater than costs of boiler only or not (orange).

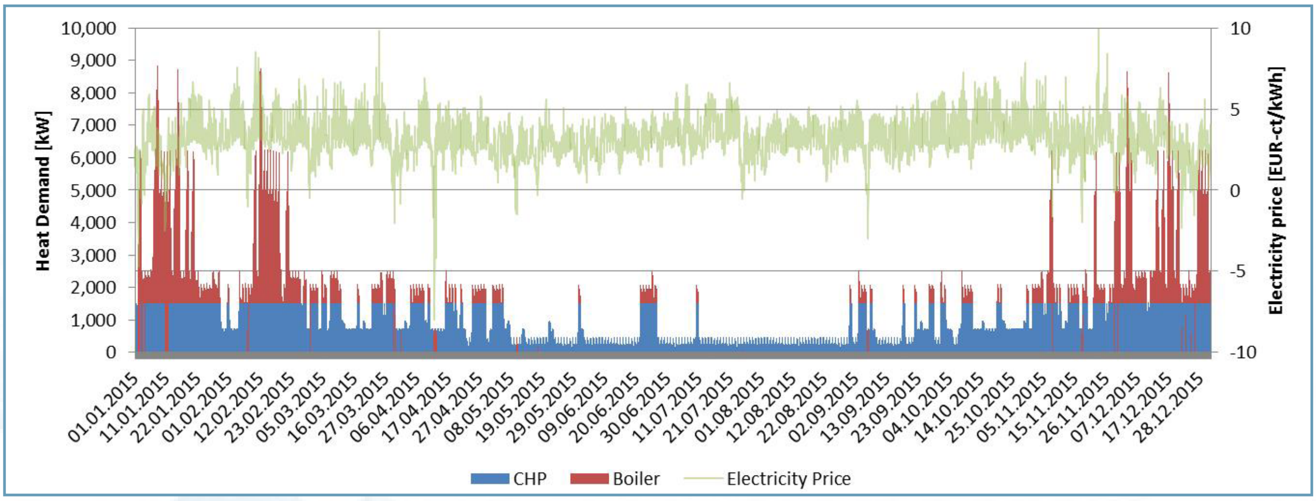

Figure 6-4 Economic operation – use of technologies depending on the occurrence of negative electricity prices (green line, right axis)

For negative electricity prices the operation costs of the CHP plant are higher than the boiler operation costs. Thus, the boiler only supplies heat to the grid. If the electricity price is not negative, the next branch asks if the heat load of the grid is greater than the maximum thermal output of the CHP unit. If not, the CHP unit is not operated under full load, which influences the cost calculation. This involves e.g. revenues from CHP bonus, grid usage costs, energy tax and fuel price. If the operation costs of a "CHP+Boiler" system are greater than the "Boiler only" system, the heat supply is then only operated by the boiler.

6.5.4 Application of EDA in a Case Study

In the present case study a district heating (DH) system of a cogeneration plant and a boiler is considered to supply about 140 multi-family houses based on the data description of (Pietruschka et al. 2016). Two aspects are analyzed: grid temperatures (standard DH vs. low temperature DH) and the operation mode (technical vs. economic operation) of a DH system.
The aim is to find out what impact has a decrease of grid temperatures and the operation mode on carbon emissions, the use of technologies and costs of the DH system.

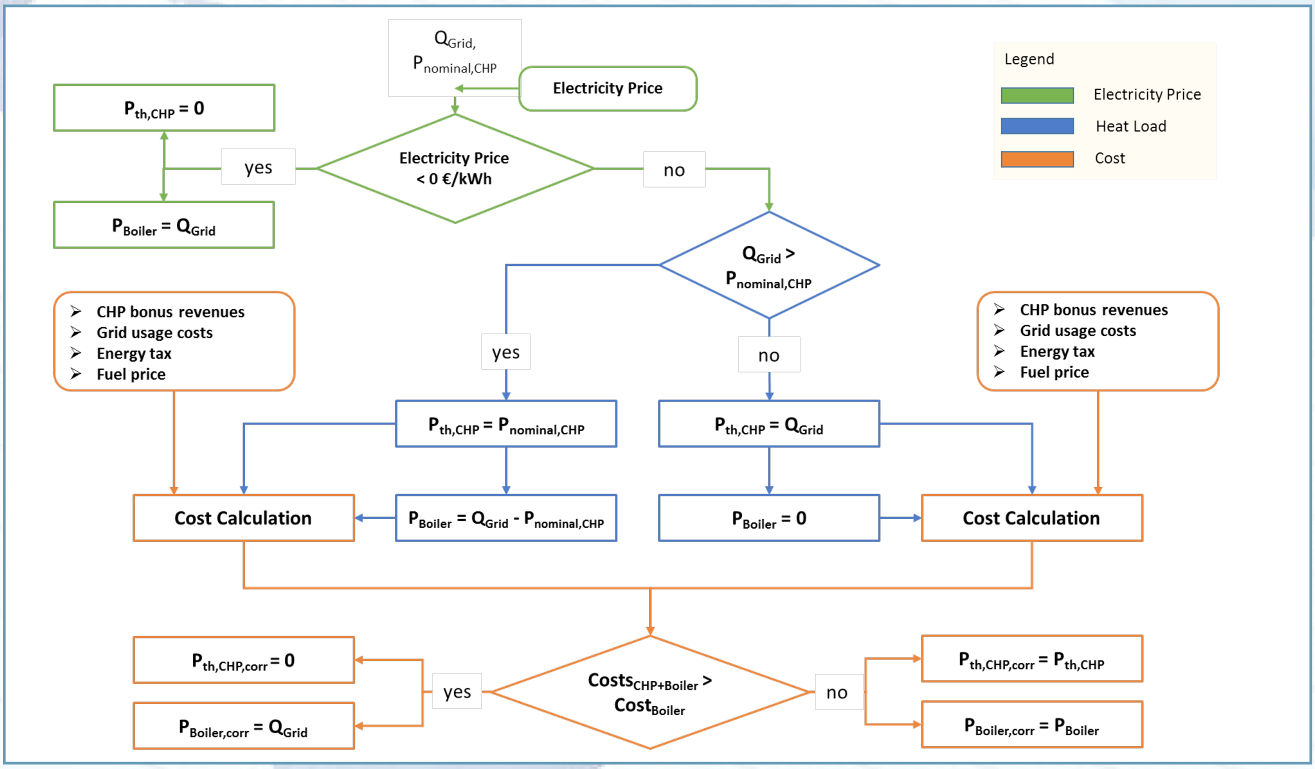

Figure 6-5 Flow chart in case of economic optimization

The motivation for low temperature DH is that a reduction of temperatures compared to standard DH involves higher efficiencies along the district energy system resulting in falling primary energy consumption and carbon emissions. Low temperature can be used, because high temperature levels are often not required for the supply of space heating and domestic hot water. For instance, radiators only need temperatures between 55 °C and 90 °C, panel heating between 35 °C and 45 °C and floor heating systems between 25 °C and 35 °C. Moreover, low temperature DH allows the easy integration of renewable energy and opens up new potentials of low energy supply (such as solar thermal and geothermal energy or waste energy).
For the present case study of an urban district of 140 multi-family houses two scenarios are analyzed in the following:

1. It is distinguished between technical (TechOp) and economic operation (EconOp) of DH to analyze the impact of economic conditions on carbon emissions.
2. The impact of solar integration on the use of DH technologies, carbon emissions and costs (EconOp+Storage+Solar) is analyzed compared to (TechOp).

Furthermore, for both scenarios a distinction is made between standard DH and low temperature DH. They are both operated with flexible supply temperatures that depend on the ambient temperature:

- Standard DH: supply from 90 °C to 70 °C / return from 60 °C to 55 °C
- Low temperature DH: supply from 60 °C to 50 °C / return from 45 °C to 35 °C

The operation optimization of the use of technologies is performed for German baseload electricity prices in 2015 and for the German CHP bonus (KWKG 2016). Although full-costs analysis takes temporal development of prices (e.g. the expiration of CHP bonus after 30,000 full load hours) into account, the operation optimization is limited to the economic conditions of the year 2015 (German CHP bonus, German electricity baseload prices, etc.).
A listing of all assumptions and inputs as well as further scenarios can be found in (Blesl and Stehle 2017).

TechOp vs. EconOp

A comparison of relative CO_2 emissions between standard DH (left) and low temperature DH (right) is shown in Figure 6-6. The reference for this calculation is the case of standard DH in technical operation mode. Carbon emissions are allocated according to the exergy method (left column) and to the power bonus method (right column).
Technical operation (TechOp) and economic operation (EconOp) play a different role in carbon emissions. Due to the economic situation (e.g. declining electricity baseload prices for electricity feed from cogeneration) the CO_2 reduction potential of DH is not exploited to the possible extent. However, the economic operation mode can perform better in carbon emissions if grid temperatures are decreased. Compared to technical operation of standard DH, low temperature DH in economic operation can even save up to 13 % of CO_2 emissions. Thus, low temperature DH can contribute to climate protection even under economic conditions. The comparison also shows for TechOp a possible carbon reduction potential of low temperature DH of up to 15 % for the present case study.
These values apply to operation optimization under consideration of the German CHP bonus. However, as the German CHP bonus is limited to 30,000 full load hours, it can be expected that carbon emissions of economic operation will then rise significantly.

TechOp vs. EconOp+Storage+Solar

The independency of DH supply from the used energy source enables the use of climate-friendly technologies, such as solar thermal energy. The integration of solar thermal energy into the DH system causes feedback on the use of the DH supply technologies. Two DH systems are compared in the following: cogeneration plant with boiler in technical operation (TechOp) and cogeneration plant with boiler along with solar integration and thermal storage in economic operation (EconOp+Storage+Solar). The cogeneration plant is designed on 5,000 full load hours for the case of technical operation. The collector surface is set at 10,000 m² (corresponds to solar fraction of round 30 % in case of standard DH). For the design of

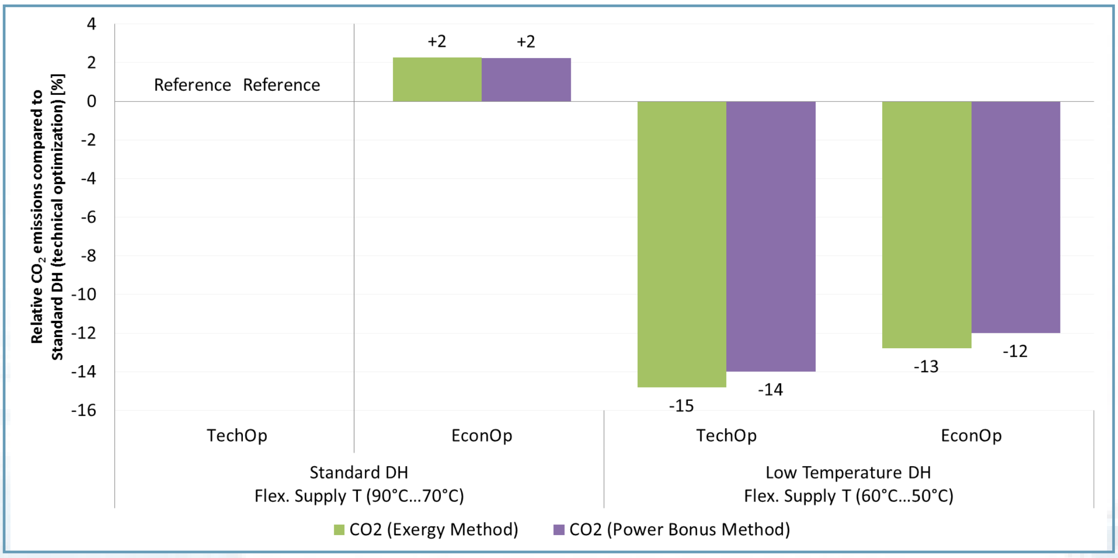

Figure 6-6 CO_2 emissions for standard DH (left) and low temperature DH (right) compared to standard DH for technical operation (consideration of CHP bonus) depending on the allocation method.

the DH storage 3.5 m³ per m² solar collector are assumed resulting in a total capacity of 35,000 m³. Still the capacity might not be enough to store all of the provided solar energy (e.g. for standard DH: about 9 % of solar energy cannot be used; low temperature DH: 26 %).

Figure 6-7 shows the impact of solar integration on the use of the cogeneration plant. In case of standard DH the share of cogeneration on DH supply drops from 66 % to 40 % respectively the full load hours decline from 5,000 to 3,000. For low temperature DH the declines are even higher: the full load hours are nearly halving from 5,000 to 2,600. However, the share of solar energy increases to 35 % for low temperature DH instead of 27 % for standard DH. To decouple demand and solar availability, most of solar energy is stored in the seasonal storage. The effect of the shift in the use of technologies on carbon emissions and costs of DH needs to be analyzed. A lower usage of cogeneration results in fewer revenues from electricity feed. On the other hand, fuel costs are decreased as solar radiation is free of charge. As solar energy mostly replaces cogeneration, carbon savings are not as high as expected. In reality, CO_2 savings are higher as boilers are not only used for peak load, but also for low loads in summer.

The quantitative effects of solar integration into the DH system for the present case study are shown in Figure 6-8. In case of standard DH solar integration with storage involves higher costs (+ 38 %), but saves up to 9 % of carbon emissions compared to technical operation.

Compared to standard DH, decarbonization involves fewer costs (+ 26 % instead of + 38 %) with low temperature DH. The reduction of carbon emissions is standing out with round 30 % compared to round 10 % of solar integration for standard DH. Due to lower temperatures solar yield from the collector field is increased by 45 % from 370 kWh/m² (standard DH) to about 540 kWh/m² (low temperature DH). This is not only explained by lower collector heat losses, but also by an increasing period of solar thermal feed (+ 32 % hours of solar feed) as lower grid supply temperatures are easier achieved. Moreover, low temperature DH increases the solar fraction of DH supply. Due to higher efficiencies of solar collectors, storage capacities in m³ need to be designed larger per m² collector surface or vice versa, for a given storage capacity less collector surface is required. Thus, above presented cost benefits would be higher, if the design of the collector field would be adjusted to reduce solar excess heat (that cannot be further stored).

In conclusion, the case study has shown that low temperature DH can be a key approach to decarbonize DH supply. The trend for rising carbon emissions of CHP DH supply (due to economic conditions) can be countered by low temperature DH even in economic operation, as less CO_2 emissions are released compared to standard DH in technical, CO_2-optimal operation (in case of

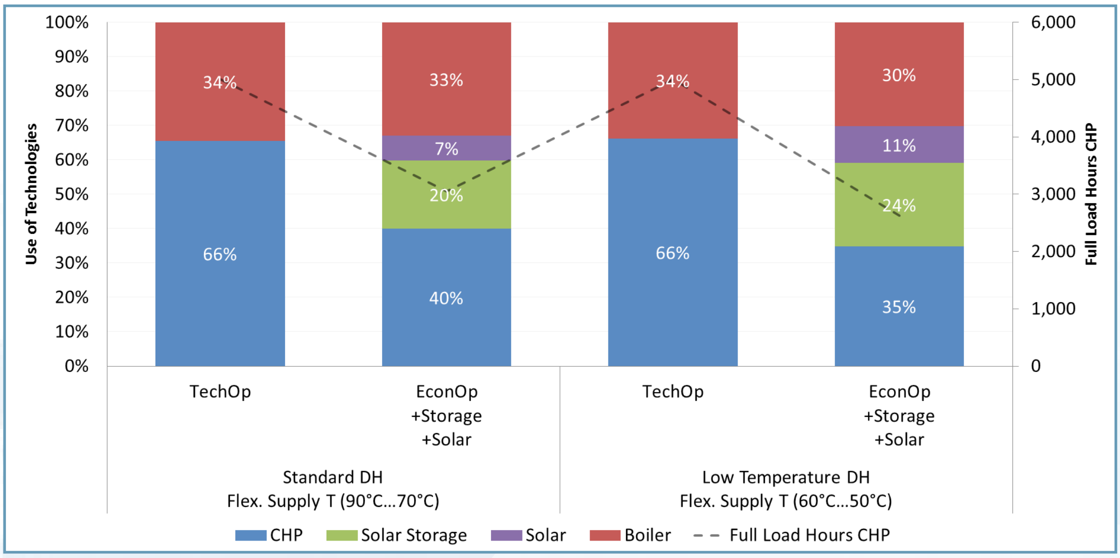

Figure 6-7 Use of technologies for DH supply in case of standard DH (left) and low temperature DH (right) and number of full load hours of the cogeneration plant (dashed line)

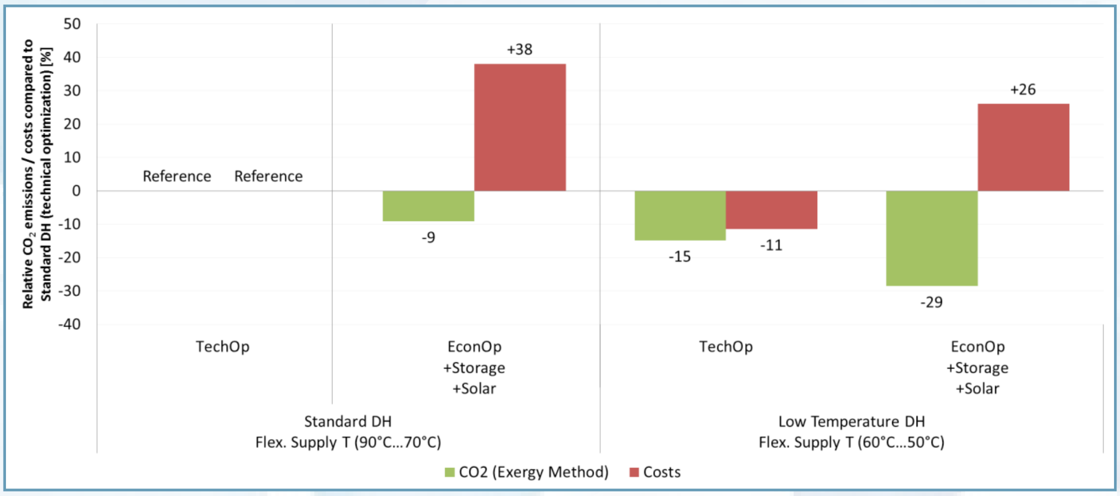

Figure 6-8 CO_2 emissions (green) and costs (red) for standard DH (left) and low temperature DH (right) compared to standard DH for technical operation

CHP bonus). Furthermore, low temperature DH with solar integration does not only increase carbon savings (e.g. due to increased solar yield and solar fraction), but also decreases costs of solar DH compared to standard DH. However, solar DH still involves - despite free of charge solar energy - additional costs compared to TechOp for the present case study.

6.5.5 Conclusion and Outlook

The Easy District Analysis (EDA) tool was developed on the basis of requirements for a simplified DH planning tool that were derived from a survey on local and DHC models. The target groups of EDA are urban planners and utilities, and it is intended to be used in the pre-planning phase of a district energy system. The focus of the EDA tool lies on the evaluation of the impact of different grid temperatures (e.g. standard DH vs. low temperature DH) and of different operation modes (technical vs. economic operation) on the use of DH technologies, primary energy consumption, carbon emissions and heat production costs.

To enable the easy district analysis, a load curve of space heat and domestic hot water is generated. The design of the cogeneration plant and boiler is based on the load curve and preset full load hours. Solar collector surface can be designed on e.g. solar fraction. After the capacities of technologies are calculated, the use of different DH supply options can be compared in terms of technical and economic operation. Technical operation leads to minimum carbon emissions, whereas economic operation means the hourly cost-effective operation of DH technologies based on fuel costs and varying revenues from electricity feed. Economic conditions, such as the development of the electricity baseload price, hinder the realization of the carbon mitigation potential of CHP DH supply to its full extent.

A case study applied to a district with 140 multi-family houses has shown that low temperature DH can play a key role in the decarbonization of DH supply. On the one hand, the trend of rising carbon emissions in CHP DH supply due to economic conditions can be countered by low temperature DH (with CHP bonus). With higher efficiencies for low temperature DH, carbon emissions are up to 13 % fewer for economic operation compared to standard DH in technical operation (with CHP bonus). On the other hand, compared to standard DH, low temperature DH can boost solar DH in terms of yield and solar fraction significantly and thus, increase the carbon mitigation potential of solar-powered DH. Moreover, heat production costs are reduced considerably by low temperature DH compared to standard DH.

The future development of the EDA tool can cover several aspects. Although EDA performs a full-cost analysis over a chosen time horizon, operation optimization of the use of DH technologies is limited to the conditions of the base year so far (e.g. electricity prices, CHP bonus). Thus, the temporal development of economic parameters could be also included for the operation optimization (e.g. to evaluate the shift of the use of technologies, after the end of 30,000 full load hours with CHP bonus or to evaluate future falling electricity baseload prices). The EDA tool could also be extended by further renewable technologies (e.g. geothermal energy, industrial waste heat) and power-to-heat technologies (e.g. heating element, heat pump), in order to find out how these multiple energy sources can be combined to best use their potentials within the context of technical, economic and ecological aspects. Moreover, issues on self-consumption vs. feed of cogeneration electricity of a district could also be taken into account. Aside DH, district cooling (DC) could be implemented in the EDA tool to consider cooling demand.

To identify suitable districts for the realization of low temperature DH, the initial heating and building standard situation along with costs for change of energy carrier could be considered. Going beyond the simplified consideration of technologies in terms of annuities, competing DH and non-DH technologies could be compared from the actor's perspective. On the one hand, the investment decisions need to be disaggregated to different actors (instead of one aggregated homo oeconomicus actor). On the other hand, preferences of actors for attributes of technologies could be considered with a multi-attribute utility analysis approach. Based on technical and socio-economic criteria, districts could then be analyzed on their suitability to be changed to low temperature DH. Thus, a comprehensive comparison could be drawn between districts to identify qualified districts to start with the transformation to low temperature DH. Moreover, actor-specific measures could be identified to support the implementation of low temperature DH.

7 APPLICATION OF LOW TEMPERATURE DISTRICT HEATING TO COMMUNITY CASE STUDIES

7.1 Introduction

The main topics for the description of case studies in this chapter are the identification, demonstration and collection of innovative community level energy concepts. Advanced technologies and the interaction between components within a system are demonstrated. Based on the evaluation of the collected examples of 4th generation district heating (4GDH), the tools developed (see chapter 6) and the implementation of combined dynamic analyses of DH technologies (chapter 4) and other relevant factors for the market implementation (chapter 5) show the potential of the approach for district heating systems. Within this chapter already realised low temperature community energy system concepts as well as planned or designed systems are identified and presented. Based on the experiences, design guidelines are derived. Also, validation of the models and tools developed within the Annex (chapter 6) using measured data from these community projects is carried out.
Main work items in the project are:

- Application of advanced system concepts including solutions for the distribution, local generation and energy storage
- Use of innovative control concepts and strategies for a demand controlled supply
- Collection of realised community projects
- Validation procedure of community design and planning tools.

The report describes eight demonstration activities in total within Europe, each reported within a single sub-chapter. The case examples are from United Kingdom (UK), Germany, Finland, Denmark and Norway. More details about the cases can be found in the full case studies report (Rämä and Sipilä 2016).

7.2 Innovative community case studies

For the description of cases each of the following sub-chapter includes a general overview of the studied system, technical description of the technologies used and the main results and outcome. In addition, many also include information of the related project and the involved stakeholders, measurement data monitoring and utilization as well as methods used.

7.2.1 Low temperature energy efficient district heating in Slough (UK)

The Greenwatt Way scheme and Slough (United Kingdom) is a research project aiming to understand the actual consumption of heat and electricity usage within an energy efficient environment. The development comprises of a mixture of two and three bedroom family homes and one-bedroom flats. The houses, compliant with the Code 6 of the Code for Sustainable Homes - CSH (The Code for Sustainable Homes is the UK national standard for the sustainable design and construction of new homes. A star system, 1 to 6 stars, is used to rate the performance of a new homes in terms of energy efficiency as well as choice of materials, water conservation and ecology), are provided with heat from a range of renewable heat technologies via a mini District Heating (DH) system whilst integrated solar photovoltaics (PV) tiles on the roof provide renewable electricity. Figure 7-1 illustrates the included neighbourhood.

The development consists of two 1-bedroom flats, a terrace of three 2-bedroom houses, a terrace of three 3-bedroom houses and two 3-bedroom detached houses with an overall heated area of 845 m².
Each home is fitted with one substation with direct connection for space heating and an instantaneous heat exchanger for DHW. Located in the living space of each home, one radiator supplies heat together with and a towel rail in the bathroom. Radiators are designed for temperatures of 55/35 °C. The homes also feature a Mechanical Ventilation Heat Recovery System (MVHR) that allows reaching the Heat Loss Parameter of 0.8 W/m²K required by CSH. The heat re-

Figure 7-1 Visualization of the included neighborhood Greenwatt Way.

covery system is supplied by the radiator circuit and allows further cooling of return temperature. This setup with radiators connected in series with heat exchangers of the ventilation system was effective at bringing the district heating return temperature down.

The scheme is designed to operate at a constant temperature of 55 °C; domestic hot water is supplied at 43 °C via the instantaneous heat exchangers. The energy centre includes the following energy sources:

- 20 m² of solar thermal panels
- 2 x 17 kW ground source heat pump each with 7 boreholes
- 2 x 20 kW air source heat pump
- 30 kW biomass boiler
- 8000 l thermal storage

Each technology, solar thermal excluded, has been sized to meet the overall requirement of the site. The ground source heat pumps, the air source heat pumps and the biomass boiler can work independently and each of them is able to meet the full heating demand of the development.

The thermal storage allows the plant to run with greater flexibility and efficiency e.g by allowing the solar thermal to charge the storage when the solar irradiation is high. The stratifying thermal storage features multiple connections to allow staged heating by heat pumps i.e. water first heated up to 45 °C by the first heat pump cycle and then up to 55 °C by the second heat pump cycle. The mini district heating network is built with a mixture of Logstor steel pipes and Aluflex pre-insulated twin pipes. The main pipeline is 98 m long with diameters ranging from 50 mm to 32 mm. Connection pipes are 67 m in length with a diameter of 25 mm (twin steel pipes for flats and information centre) and 26 mm (twin Aluflex pipes for houses). The network layout is visualised in Figure 7-2.

The annual heat consumption of the dwellings is 35.7 MWh. The heat supplied by the energy centre amounts to 49.6 MWh/year, indicating heat losses of 28 %. The demonstration was implemented between December 2009 (construction was started) and September 2010 (development occupied). The monitoring period was a year from 4/2011.

Figure 7-2 Layout of the district heating network.

Table 7-1 Summary table for the main indicators for Greenwatt Way system.

Overall length of the pipeline trench	165 m
Heat consumption	35.7 MWh/year
Heat delivered from energy centre	49.6 MWh/year
Average heat losses	28 %
Linear heat density	0.319 MWh/m
Average temperatures (supply and return) during the heating season	51.7/31.7 °C
Average temperatures (supply and return) outside the heating season	50.5/38.5 °C

Main activities within the project were:

- Post occupancy evaluation
- Modelling and monitoring of the energy performance of the energy centre, district heating and domestic heat and power demand
- Evaluation of the MVHR
- Monitoring of PV generation
- Monitoring of water usage
- Evaluation of hot fill washing machine and dishwasher

Lead organisation, the developer and the owner for the system was SSE, the research partners being National House Building Council (NHBC), Building Research Establishment (BRE) and University of Reading. The total budget for the demo was £3.65 million. The demonstration system received support in the form of feed-in tariff for the large PV arrays on each house, but no support for the heating system itself.

The main deliverables for the project were:

- Evaluation of energy consumption in nearly zero carbon houses
- Evaluation of users interaction with nearly zero carbon house systems
- Demonstration of construction techniques deployed to build nearly zero carbon houses

7.2.2 Energy efficient district heating network in Ludwigsburg (Germany)

The German Renewable Energies Heat Act (EEWärmeG) states that the share of renewable energy in heat generation in Germany is to be increased to 14 % by 2020. The expansion of district heating systems is seen as an important element in achieving this goal. District heating enables easy integration of renewable energy sources and results in higher efficiencies in energy conversion. The use of combined heat and power in heating grids is an additional option. However, existing district heating networks are often not sufficiently optimised. Systems suffer from high heat losses, high return temperatures and high electrical consumption in pumping. Deviations between predicted and measured temperatures, pressures and mass flows are very common. Reasonable planning and operation of the systems can potentially increase their energy efficiency. The economics involved drive many heating system operators to be hesitant over combining renewable options with existing centralised heat production.

Decentralised heat supply for small or isolated areas or so-called micro-grids in many cases are preferable to an uneconomical expansion of existing district heating networks. In these systems, decentralised solar heating can help saving costs during summer periods when energy demands are very low (only DHW) (see also 7.2.4). So it may be more cost efficient to utilise decentralised heat supply than to operate centralised heat generation in partial load.

The main objectives of the project are to develop a simulation environment for efficient integration of decentralised renewable heat sources in existing or planned heating grids. Applicable results are to be implemented on a real heating network in the Sonnenberg district of Ludwigsburg.

Sonnenberg has a new district heating grid supplied by a gas CHP plant combined with a geothermal heat pump. Both are located in an old heating plant now refurbished and reopened. The municipal energy supplier, Stadtwerke Ludwigsburg-Kornwestheim GmbH, installed and will operate the planned new district heating. All purchase contracts for the Sonnenberg building sites in-

clude a clause making the connection to the district heating network compulsory.
The gas CHP unit has a capacity of 350 KW_{th} and the geothermal heat pump a capacity of 200 KW_{th}. The buildings are equipped with a substation and decentralised heat storage tanks.
Also, smart metering with a centralised control unit is installed in the buildings. The new distribution system's design includes an optional low exergy expansion with temperature levels (40/25 °C). The design temperatures of the main network are 70/40 °C and thus, significantly higher.
30 % of the new Sonnenberg district, supplied by the LowEx subnet (blue area) is planned in to achieve the low energy or passive house standard. Thus, the planned grid extension can be operated by the return line of the existing grid. The layout of the distribution network is presented in Figure 7-3.
The project focuses on heat demand evaluation by studying the operation of the grid. Special attention is paid to the management of heat supply and storage tanks' charging strategies. Detailed grid simulations help to optimise system operation.
Stuttgart University of Applied Sciences (HFT Stuttgart/Germany) acted as the project lead while the implementation was carried out by Stadtwerke Ludwigsburg-Kornwestheim GmbH, which also owns the system. The demonstration project was started on 1st January 2012 and was concluded on 31st August 2014.

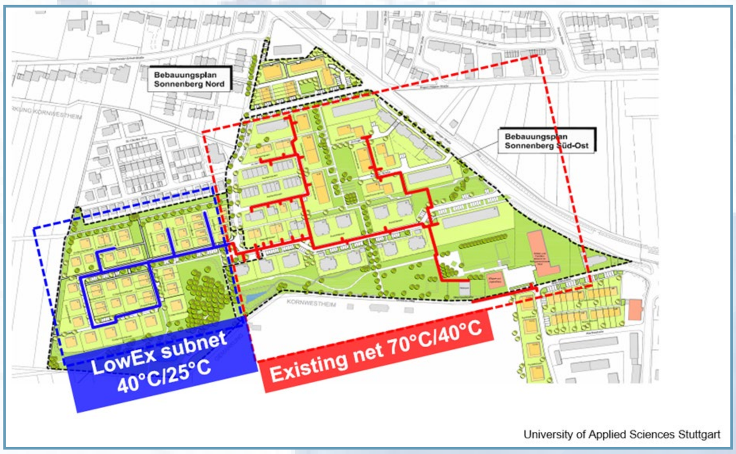

Figure 7-3 Overview of the existing and planned district heating network in Ludwigsburg

The main results of the project are:

- Development of a substation for active consumers allowing bidirectional heat transfer to and from the district heating network
- Testing facilities for validation of numerical simulation models
- Simulation based optimisation of network control
- Creation and validation of an overall network model of city quarter Sonnenberg Including numerical models for heat generation units, distribution network and detailed consumer models

7.2.3 Residential area with geothermal heating & cooling in Wüstenrot (Germany)

A strategy for making Wüstenrot (Germany) a plus energy community by 2020 was developed within the EnVisaGe project. This means that the community's yearly energy production would be more than the actual energy consumed within the community. As one important step towards that goal, a plus energy residential district with 24 mostly single-family houses was built.
To achieve the plus energy standard for all buildings, a high energy standard - almost passive house standard - was demanded by regulation. All buildings are equipped with large PV systems. The heating energy of the buildings is delivered by decentralised heat pumps. The heat pumps are connected to a central geothermal system. Thus, they can achieve a high coefficient of performance. This system consists of a cold water district heating network, delivering low temperature heat to the heat pumps. The novel agro-thermal collector is used as a low temperature heat source for the network. The concept of the system is to activate agricultural fields as geothermal collectors. This is done by deep ploughing the tubes 2 m below the ground surface, interspaced at a distance of 1 m. The process is pictured in Figure 7-4. The agro-thermal collectors can also be used for direct cooling of the buildings during summertime. This is in addition to using the cold water network for heating during the winter period.
Furthermore, the system offers the possibility to combine heat sinks (heat pumps) and

Figure 7-4 Thermal activation of the agricultural field in Wüstenrot © HFT Stuttgart

heat sources (e.g. re-cooling of compression chillers) for highly efficient energy use. In the demonstration system, this combined utilisation is being demonstrated and analysed by integrating the re-cooling of a supermarket cooling device. This supermarket is located near the plus energy district. A special technology for this is being developed by the company Doppelacker, which is based in Berlin, Germany.
The overall objectives of the project were to:
Demonstrate the efficiency and economic viability of cold water heating/cooling grids with agro-thermal collectors

- Show the efficiency of the connected decentralised heat pumps and of direct cooling applications in the buildings
- Demonstrate the combined performance of the system with heat sinks (heat pumps) and heat sources connected (re-cooling of the super market cooling device)
- Development and testing of intelligent load and storage management to increase own-consumption of PV electricity
- Offer electricity sinks to the municipality's distribution grid by connecting the virtual power plant
- Development and implementation of an innovative and secure cloud based solution for data collection and transfer
- Development of an intelligent load management system

The objectives were met by following deliverables:

- System installation of the agro-thermal collector
- Connection of 16 buildings to the cold water heating grid
- Monitoring data of at least 6-8 buildings for one year (in progress)
- Monitoring data of the agro-thermal collector fields and cold heating grid (in progress)

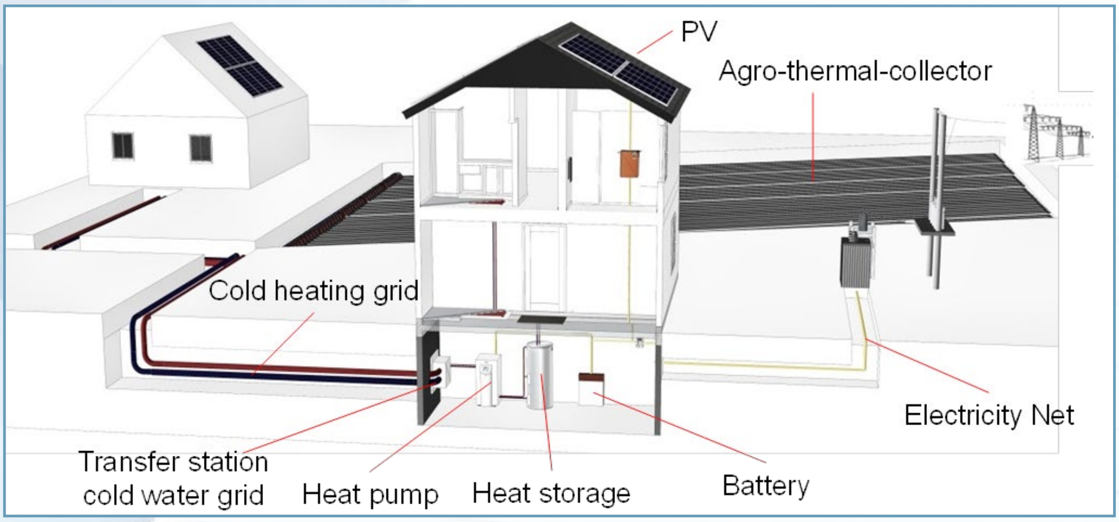

Figure 7-5 Connections between buildings and the energy system in Wüstenrot

- Simulation model for the agro-thermal collector (to be further validated during the monitoring phase)
- Development and implementation of an intelligent load and storage management.

The project duration is from July 2012 to June 2017. A project extension for monitoring is planned for a runtime of 3 more years, which will be followed by a long-term monitoring phase.

7.2.4 Geo-solar local heat supply for residential area in Kassel (Germany)

The case system area „Zum Feldlager“ is located in Kassel in the center of Germany. Currently the area is undeveloped land on which a new housing development is planned. The area is surrounded by existing buildings and there is a water protection area nearby. The new housing estate “Zum Feldlager” is located in an urban ventilation path. For that reason, combustion of oil or wood (with possible fine particles) should be avoided. Due to the location of the area, a connection to the existing district heating network of Kassel is not feasible because of logistical and economic reasons. As a result, a local district heating concept is implemented. The concept involves the use of renewable energy sources (RES) such as geothermal and solar energy for low temperature district heating and domestic hot water supply.

Figure 7-6 Preliminary urban planning concept for the new housing estate ”Zum Feldlager” © Architektur+Städtebau Bankert, Linker & Hupfeld

The new housing estate will be characterized by a very compact construction and south oriented buildings; 1-2 storey detached and semi-detached houses in the north, two-storey terraced houses in the centre and large three-storey apartment buildings in the south. All buildings have specific heat demand of 45 kWh/m²·a and a specific domestic hot water (DHW) demand of 730 kWh/person·a. Thus, the demand is significantly below the maximum energy demand for new buildings (<50 kWh/m²·a for heating) according to the current valid German energy saving ordinance EnEV 2014 (EnEV 2014).

The system consists of a centralized heat pump powered by borehole heat exchangers (BHE) installed in a geothermal probe field. Depending on the supply variant, the soil acts as source in winter or as thermal storage in summer time. For the regeneration of the soil unglazed solar collectors (swimming pool absorbers as the low-cost option) are intended. The district heating grid is fed by the centralized heat pump. It is conceivable to use the district heating during heating period for provide (low temperature) heat. The centralized ground coupled heat pump feeds the district grid at a temperature level of about 40 °C. The heat for space heating is supplied directly by the district heating network through the use of heat exchangers. For preparation of domestic hot water different variants are possible and foreseen. In case of separated domestic hot water pre-

Table 7-2 Assumptions for the buildings and climatic boundary conditions according to the first planning

Total number of buildings	127
Single-family houses (SFH)	46
Semi-detached houses (SDH)	32
Terraced houses (TH)	37
Multi-family houses (MFH)	12
Dwelling units	154
Persons per dwelling unit	4
Climatic conditions	2010
Orientation of buildings	south
Roof shape	SFH, SDH and TH = gable roof, MFH = flat roof
Heat emission system	surface heating

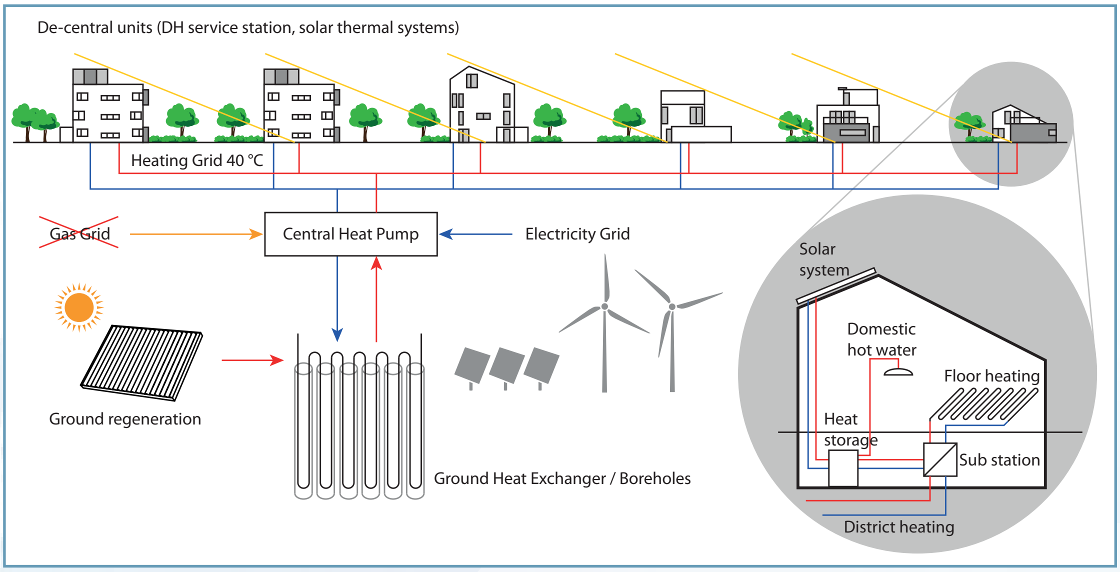

Figure 7-7 Arrangement and schema of the solar-ground storage systems © Fraunhofer IWES

paration thermal solar panels (e.g. flat-plate collectors) or an electric heating element could be used. The solar panels could be installed on the roof or on carports. Another variant for domestic hot water preparation is usage the heat of the district heating grid, also in combination of solar panels and heating elements. The required temperatures lift is significantly lower.
The advantages of this supply variant are slightly higher heat losses. Furthermore, space heat could be directly used from grid (substation required). No decentralized heat pumps must be installed and thus the investments costs are lower.
The research effort in the project was carried out by Fraunhofer IBP/IWES and University of Kassel (Department of Geotechnical Engineering & Department of Solar and System Engineering). The owner of the demonstration system was City of Kassel and the operator was the utility company Städtische Werke AG in Kassel. German District Heating Working Group (AGFW) was also involved in the project. The project started in 11/2015 and is to be concluded in 8/2017. In late 2016, the decision has been made not to realize the project approach as described here because of time constraints. The total investment costs were estimated to be 3.7 million EUR (demonstration) and 1.0 million EUR (research, measurements).
The main activities for the project were:

- Soil reconnaissance
- Development of thermal simulation model of entire housing estate
- Development of industrial management and control strategies of district heating system (winter and summer case)
- Dimensioning of components
- Measurement and evaluation concept

7.2.5 Future district heating solution for residential district in Hyvinkää (Finland)

District heating has been an integral part of the Finnish energy system for decades. Its development started in 1950's and currently sits on a market share of 48 % within the heating sector. In the major cities, the market share is over 90 %. Finnish district heating systems are characterised by high efficiencies and high share of CHP based production (up to 75 %) in heat supply. In terms of distribution, the insulations standards used in Finnish district heating pipes are high compared to most other developed district heating countries (Heikkinen et al. 2014 and Klobut et al. 2014).
The district heating system in Hyvinkää building fair area (Figure 7-8) is used a case study for low temperature district heating and for incorporating solar heating into buildings within a district heating area. Another point of view was to highlight the significance of planning by showing the effects lower than predicted connection rate. Currently, at the time of the study the connection rate within the area was 47 %. Other dwellings have chosen different heating solutions; boilers, collectors, heat pumps or a combination of

these. Most of the buildings have underfloor heating for internal heat distribution, but some have radiators or ventilation based heating systems.

Figure 7-8 Overview of the Hyvinkää building fair area © Arkkitehtitoimisto Turtiainen Oy

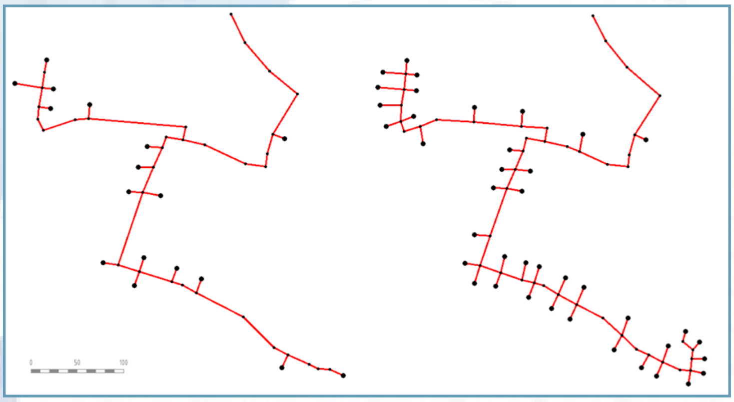

Figure 7-9 Network structure for 47 % connection rate (left) and 100 % connection rate systems.

The studied area is part of the larger Hyvinkää district heating system (Rämä et. al. 2014). The connection to the main system is implemented using heat exchangers. As a result, the distribution temperatures in the area are lower than in the main system; constant supply temperatures of 85 °C and 75 °C are used during winter and summer time, respectively. As an additional simulation effort, the operation with a constant supply temperature of 65 °C was studied as well. The distribution network in the area has a total length of 1,223 m or 1,675 m for 47 % and 100 % connection rate cases. It consists of pipes in sizes from DN40 to DN200 with service pipes being either DN15 or DN32 depending on the consumer. The network structures for both the existing (47 % con nection rate) and planned (100 %) system layout are presented in Figure 7-9.

Modelling of heat demand was carried out using IDA Indoor Climate and Energy simulation tool (space heating) and Apros Process Simulation Software (domestic hot water). The existing 47 % connection rate case had a heat demand (including heat losses) of 630 MWh and a linear heat density of 0.4 MWh/m (consumption per trench length). The planned system (100 % connection rate) had 1,371 MWh of heat demand and a linear heat density of 0.74 MWh/m.

In parallel with the simulation work, life cycle costs (LCC) analysis was carried out. According to results, the district heating solution in a single family passive house, complying with the 2020's energy efficiency requirements, is a little more competitive compared to the solution using ground heat pump. Life cycle assessment (LCA) showed that the carbon footprint of a small district heated house can be reduced by building more energy-efficient house than current standards require. Additionally, approx. 50 % of greenhouse gas emissions can be avoided during the life cycle of 25 years, by increasing the share of renewable fuels in the district heat production. Utilisation of heating and electricity generated from municipal waste will reduce the building's carbon footprint.

The study was part of a larger project called "Future district heating solutions for residential districts" (Klobut at. al. 2014) with following objectives:

- To develop adequate district heating solutions for residential low energy districts
- To compare alternative solutions by lifecycle assessment (cost and emissions)
- To evaluate the potential of utilising municipal and construction waste for district heating energy generation
- To investigate how nearly zero-energy buildings (in terms of the Energy Performance of Buildings Directive) affect the dynamics of local DH-network

The lead organisation of the project was utility Hyvinkään Lämpövoima (owner of the district heating network) and the other participating and funding organisations were Finnish Funding Agency for Technology and Innovation, City of Hyvinkää and Finnish Energy as well as energy utilities Ekokem Ltd, Jy-

väskylän Energia, Helsingin Energia, Porvoon Energia and Riihimäen Kaukolämpö. VTT Technical Research Centre of Finland was responsible for the research carried out in the project. Demonstration site was owned by the Hyvinkään Lämpövoima.
The project started in 10/2011 and was concluded in 12/2013.

7.2.6 Low-temperature district heating in Sønderby (Denmark)

The project is a full scale demonstration in Sønderby, Taastrup, in Denmark (Figure 7-10). The heated area includes 75 single family houses built from 1997-1998 with under floor heating systems. The demonstration aims to show that low temperature district heating (LTDH) works in existing buildings and identify solutions to minimise the high heat losses.
In the project, the old district heating (DH) system was replaced with new DH pipes and consumer substations. Through renovation, the temperature in the network is reduced from average 80 °C to average 55 °C. The demonstration project shows that there is a great energy saving potential by providing LTDH for existing buildings with underfloor heating as space heating system.
The demonstration area includes 75 single family houses built from 1997-98 with living space ranging from 110 to 212 m², typically 2-5 people in each house. The houses have floor heating in all rooms which make it possible for LTDH supply. The heating degree day is 2,977.
The annual heat consumption in the buildings is in the range of 5 to 23 MWh/year per house (not include heat loss in the grid). Average consumption is about 13 MWh (based on consumption during the heating seasons 2004/2005 - 2009/2010). The houses originally had hot water tanks for domestic hot water (DHW) supply (110 l or 150 l). Before the project, the network supply temperature varied between 65-107 °C, with the lowest supply temperature in summer. The average supply temperature is 80 °C. The annual grid heat losses accounted for 38-44 % (average ≈ 41 %) of the heat supplied from the central heat exchanger.
Through the project, high efficient twin DH pipes are installed to replace old very inefficient plastic DH pipes. Branch pipes are AluFlex flexible pipe with insulation class series 3. The larger pipes are insulation class series 2. The area is supplied from adjacent medium temperature DH network. Low temperature is achieved with a mixing shunt and a booster pump. All 75 houses are replaced with new instantaneous heat exchangers. The heat exchanger is specially designed for the low temperature difference and the high flow on the primary side, which is obtained by low-temperature operation with a flow temperature down to 50 °C. All 75 houses are equipped with remote reading of power meters (Kamstrup MULTICAL® 601 with top module). The supply temperature to the low temperature network has averaged 55 °C. The return temperature has annually been about 40 °C, resulting in an overall cooling of about 15 °C.

Figure 7-10 Full scale demonstration of low-temperature district heating, Sønderby, Denmark. (Energistyrelsen 2014)

The main design parameters are:
- Network maximum level of pressure: 10 bar
- Maximum velocity in pipes: 2.0 m/s
- Peak load design outdoor temperature -12 °C
- Thermostatic bypass set point 50 °C
- Heat loss coefficient (U-value) based on the supply/return temperature 55/25 °C and ground temperature 8 °C.
- Minimum differential pressure: 0.3 bar
- Taastrup DH plant supply pressure 3.4 bar

- Taastrup DH plant return pressure 2.6 bar
- Comparing with old DH system, the new DH system has the following features:
- Low network supply/return temperature
- Energy efficient and smaller dimension DH pipes
- Mixing shunt and booster pump for low-temperature supply
- New low-temperature instantaneous heat exchanger

These features result network heat loss reducing from 4 % to 13-14 %.

The low-temperature is supplied with a mixing shunt which regulates the temperature for the low-temperature network. The primary heat source comes from the return line of the medium temperature DH network. When the temperature in the return line is not sufficient, water from supply line of the medium temperature DH network will mix with return water to achieve the desired supply temperature. The system therefore consists of three pipes: two supply pipes and one return pipe.

In the full scale demonstration project, the old inefficient DH pipes were replaced with better insulated AluFlex pipes and the old water storage tank substations were replaced with low-temperature instantaneous heat exchanger substations. The heated area is supplied through a mixing shunt and a booster pump. In the project, detailed measurements and data collection were performed. These measurement data are processed and analysed for the period January 1st, 2012 to July 1st, 2013.

The demonstration project showed that it is feasible to supply LTDH to existing area with floor heating as space heating. The results show that it is possible to supply DH consumers with a flow temperature of 50 - 53 °C, which is sufficient to cover the space heating demand, and to permit the production of domestic hot water in a secure manner. Comparing with old medium temperature DH system which has average grid heat loss approximately 41 %, the new system reduces the heat loss down to 13 – 14 %. The energy efficient goal in the project has been met. The reduction in heat loss is a result of lower temperature in the DH network, and then heating pipes with better insulation properties.

The full-scale demonstration project included a new supply concept. The low-temperature network is supplied with return water from the medium temperature network from the neighbouring Taastrup DH. This supply temperature is averaged at 48 °C and the supplied energy covers about 80 % of the total supply. Its remaining supply is covered with warmer water from the supply line from the neighbouring network. The advantage of the concept is that the supply capacity of an existing district heating network can be increased without requiring any further investment costs. Moreover, it provides a lower return temperature in the overall DH network, which reduces the heat loss and can provide higher efficiency in heat generation plant. The supply concept requires that there is an adjacent area with a sufficient flow in the return line and a relatively high return temperature.

In the project, it was found that the average network supply temperature is 55 °C and return temperature is around 40 °C, which results an overall cooling of about 15 °C. The less cooling is deemed to have given a greater need for pumping energy, but this is still a small percentage compared to the total savings in losses in networks. There are several explanations for the higher return temperature, but the main reason is just too great a bypass flow in some user installations caused by defective or incorrectly set control valves. It is also considered that many consumers do not close for „summer valve" in their water heater. The problem with that consumers do not get closed summer valve may in future projects may be handled with electronic, supplemented with a return temperature limiter on space heating heat exchangers.

Project lead was by COWI A/S and other participating organisations Danfoss A/S, Logstor A/S and Kamstrup A/S. The owner of the demonstration site was Taastrup District Heating.

7.2.7 Sea water heat recovery and heat pumps in Ulstein (Norway)

In Ulstein (Norway), “Fjord” district heating is based on utilisation recovered heat from the sea and decentralized heat pumps. The recovered heat in low temperature is distributed to substations. Both heating and cooling is distributed using the same pipe network without any insulation. Low water temperature results in low heat losses and low operation cost. The local energy substation can be used for one or few buildings. The solution is suitable for locations on the coast. In Ulstein project, the sea water temperature was measured to be from 4 °C to 9 °C during the year at the depth of 42 m. In total about 15 energy substations will be connected to the system.
In the beginning, 20 % of the customers are included in the district heating system. After five years, the connection rate will be up to 60 % and after 10 years 100 % of the capacity will be utilized. Additional capacity of 20 % as reserve is assumed to be utilized within 20 years. The total heat supply delivered by the district heating system will be higher than 10 MW within five years. Including the reserve capacity the plant should deliver about 20 GWh heating and 5 GWh cooling. It was assumed that the heating and cooling price will be about 0.7 NOK/kWh (1 NOK ≈ 0.113 EUR).
The total investment within the first 10 years will be about 75 million NOK and 85 million NOK within 20 years.

Figure 7-11 Pipelines for supplying water used as a heat source for heat pumps in a district heating system in Ulstein
© Øyvind Amdam, Ulstein municipality

7.2.8 Lower temperatures for existing systems in Middelfart (Denmark)

The district heating company in the Danish city Middelfart has been supplying heat to their consumers since 1963. During the past 7 years, the company has been working hard to lower the temperatures in the district heating network, that now delivers heat to approximately 5000 customers. This has resulted in a case project where supply and return temperatures have been lowered from an average of 80.6 °C / 47.6 °C in 2009 to an average of 64.6 °C / 40.0 °C in 2015. The district heating company has taken part in the development and test of software tools that can help in reducing the return temperature in district heating networks. Furthermore, the company has demonstrated a process that district heating companies can follow when working towards a low-temperature operation profile. During the process the network heat losses in Middelfart have been lowered by almost 25 % and the economic benefits where estimated to approximately 5.5 million DKK/year (0.7 million EUR/year). Thereby, the case project demonstrates that it is possible to obtain large energy savings by optimizing the district heating temperatures in existing networks.
Middelfart district heating supplies heat through two district heating networks, one in the city of Middelfart and one in the smaller nearby village Nørre Aaby. In Middelfart the district heating network consists of approximately 139 km of pipe and supplies heat to approximately 5000 customers. Customers cover a large range of different buildings but consist mainly of small customers such as single-family houses and few larger customers such as schools. The building mass in the city ranges from old buildings to modern low-energy buildings. Middelfart district heating is a distribution company, which means that they do not produce the heat, but buy it from a local heat supplier. The heat mainly consists of surplus heat from an oil refinery, CHP production, and heat from a waste incineration plant. The annual heat consumption in the city is approximately 480,000 GJ per year. Key numbers for Middelfart district heating are seen below and the heating network in Mid-

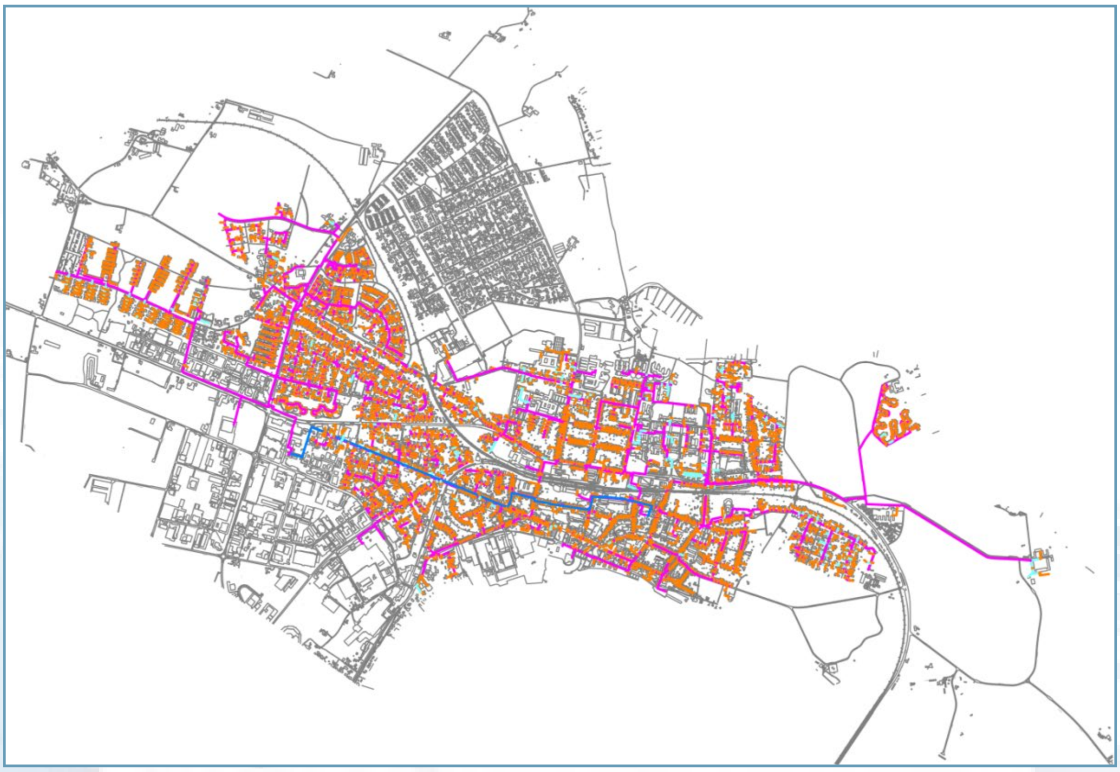

Figure 7-12 Illustration of the district heating network in Middelfart © Illustration Middelfart District Heating.

delfart is illustrated in Figure 7-12.
Apart from development of software solutions in Termis (Schneider Electric 2017), the project also aimed to collect experiences on the practical work with Return Temperature Optimisation (RTO). The developed software was installed amongst others at Middelfart district heating and the district heating company planned a process to lower the district heating temperatures. This process required a new vision of the services provided by the district heating company and a large amount of customer communication. Whereas the district heating systems are commonly considered to cover only heat production and distribution, Middelfart district heating expanded their service to include customer installations inside the buildings, as the operation of the district heating substations were continuously monitored by the district heating company. The district heating company was provided with an overview of customers that need to make a long term effort to lower a high return temperature, or customers that experience a malfunction in their installation leading to a sudden increase in the return temperature. If a substation is seen to provide a high return temperature, the district heating company offers a service check and provides advice for the customers on how to improve their heating installation. This is both a benefit to the customers, who receive additional service from the heating company, and for the company, as the return temperatures are continuously lowered in the network, when old inefficient installations are replaced. The service was provided by an employee that continuously monitors the operation of the district heating network on the basis of the new tools for data collection and Return Temperature Optimisation.
When the return temperature is lowered, the price of the district heating becomes more favourable as heat losses are lowered, and production efficiency is increased. In order to motivate the customers to improve their heating installations and provide a more fair distribution of the actual heat price on each consumer, the district heating company introduced a return temperature tariff in their pricing structure. This tariff provides customers with a low return temperature with a financial bonus while customers with a high return temperature pay an extra cost according to the costs imposed on the district heating company due to higher heat losses and lower heat production efficiency. The district heating company made a large effort to advertise the new service provided and inform

about the new return temperature tariff that was implemented. The experiences from the project therefore include successful implementation of a new district heating strategy where customer substations are included in the service area of the district heating companies and customers pay, not only for their heating consumption, but also for the actual cost they impose on the heating system.
Temperature optimisation provides a large number of benefits for the district heating company. First of all, the heat loss from the pipe network is reduced when network temperatures are reduced. Reduction in return temperature furthermore ensures more energy efficient heat production from heating plants with flue gas condensation or heating plants based on for example solar heating. Additional benefits include the fact that when the return temperature is lowered, the same amount of heat can be delivered at a smaller mass flow rate. Therefore, pumping energy can be reduced and network capacity increased. This can be very beneficial in district heating systems where the capacity limit has been reached, or where expansions are planned in the near future. The benefits can be summarised as:

- Lower heat loss from pipes
- More efficient heat production
- Lower power consumption for pumping
- Increased capacity in the district heating network

The demonstration project has successfully shown how temperature optimisation can be implemented in existing district heating systems, and that it can lead to large energy efficiency improvements. The project demonstrates the possibility of including customer installations in the optimisation of the district heating system, by monitoring the operation of customer substations, providing service checks for customer installations, and implementing a return temperature tariff that motivates consumers to improve heating system installations. Ultimately the project provides software and process tools that can help existing district heating companies to lower the temperatures in the networks.

The main results of the project were:

- Development of system for collection and use of smart meter data from district heating substations
- Development of extension for the real-time district heating operation software Termis, to include a module for return temperature optimisation
- Demonstration of the use of smart district heating meters and software for return temperature optimisation in existing district heating systems
- Practical experiences from the process of optimizing return temperatures in district heating networks

Project lead responsibility was on COWI A/S and Middelfart District Heating had the ownership of the demonstration. Solution developers were Schneider Electric Denmark A/S (Termis) and MeterWare. Other participating organisation was Fjernvarmens Udviklingscenter.
The project was started in 2009 and temperature optimisation is continuously carried out. Part of the demonstration was carried out through a research and development project in 6/2013 – 12/2014.

7.3 Summary and Conclusions from the Case Studies

Core objective for the description of case studies was to identify and collect innovative demonstration concepts as examples of success stories for communities interested in developing low temperature district heating systems. Demonstrated cases include use of advanced technologies and interaction between different components within the systems. Based on these experiences, principles and lessons learned in designing these systems are given. Measurement data from community projects are also used in validation of the models and tools developed.
There were a total of eight case studies from Germany, Denmark, Finland, Norway and Great Britain. The district heating systems were of very different sizes, from miniature to city wide systems. Network lengths were from 165 m to 140,000 m. The connected buildings were detached, terraced and block houses, and mostly low energy or passive houses. Sources of heat were solar

collectors, heat pumps, CHP plants, excess heat from industry or the systems were connected to a larger network close by with heat exchangers. The temperature levels recorded were typical for low-temperature systems, varying from 40 to 60 °C in supply and 25 to 40 °C in return. Savings and increased efficiencies were observed in every case studied. The Table 7-3 summarises the case systems by listing yearly heat demands and distribution temperatures as well as giving a short description of each concept studied.

Greenwatt Way in Slough (UK) has a system of 10 dwellings with 845 m² heated floor area, supplied by a miniature district heating system with a trench length of 165 m. Heat supply consist of 20 m² solar thermal collectors, two 17 kW ground source heat pumps with 14 boreholes, two 20 kW air source heat pumps and a 30 kW biomass boiler as well as a 8 m³ thermal storage tank. The total capacity of the controllable heat sources is 105 kW with added capacity from solar thermal collectors and the storage unit. The heat pumps can work in series so that at first stage water is heated up to 45 °C and at the second stage up to 55 °C. Each house is fitted with a substation with direct connection for space heating and with a heat exchanger

Table 7-3 Summary of the case study systems.

Case system	Heat demand	Temperatures	Short description
Slough (UK)	49.6 MWh/year	52/32 °C	Miniature district heating system with 10 dwellings and solar collectors, ground and air source heat pumps, biomass boiler and a heat storage as heat supply options.
Ludwigs-burg (Germany)	825 MWh/year	40/25 °C	Storage and heat supply capability in consumer substations, two-way connection to a local low temperature district heating system. CHP unit and ground source heat pumps as the centralised heat supply options.
Wustenrot (Germany)	376 MWh/year	40/30 °C	Decentralised heat pumps for each consumer, utilising heat from collector pipes buried in agricultural fields. All dwellings are passive houses with PV systems on roof-tops. Cold water network can also be used for cooling and rejection of excess heat.
Kassel (Germany)	1,827 MWh/year	40/30 °C	Low temperature district heating system for 127 buildings with heat supply consisting of solar collectors, a centralised ground heat pump with boreholes that can be utilised also as seasonal heat storage. Use of electric heating elements or solar collectors for DHW production is studied.
Hyvinkää (Finland)	630/1,371 MWh/year	65/35 °C	Building fair area with local district heating system consisting of 40 consumers. Solutions for combining distributed solar collector systems and district heating, the effect of connection rate and low distribution temperatures are studied.
Sønderby (Denmark)	975 MWh/year	55/40 °C	Complete renovation of pipe system for a part of a larger district heating system. Reduced distribution temperatures and return flow in the core network used as the main heat supply. Heat losses reduced approximately by 66 %.
Ulstein (Norway)	20,000 MWh/year	4-9 °C	Cold district heating system using sea water as the heat source for decentralised heat pumps at the consumer buildings. Can also be utilised as free cooling.
Middelfart (Denmark)	118,000 MWh/year	64.6/40 °C	Demonstration of process for lowering the supply and return temperatures systematically across a large scale system of 5000 consumers and 139 km of pipes. Issues with individual consumers mostly corrected by normal service operations. In addition to lower supply temperatures, the return temperatures could be lowered as well, reducing the effect of normally increased flow rates. Tools developed for dynamic simulation of temperature levels within the network.

for domestic hot water. Radiators are dimensioned for 55/35 °C temperatures. Domestic hot water is supplied at 43 °C. Exhaust air heat recovery systems are connected to the radiators. The houses are equipped with solar panels benefitting from a feed-in tariff. The total budget of the pilot project was £3.65 million. The project was started in 2009 and measurements were carried out from 4/2011 to 3/2012. The measured supply of heat was 49.6 MWh and heat demand 35.7 MWh indicating 28 % heat losses within the system. The average cooling in the system was 20 °C during and 12 °C outside the heating season. Relative monthly heat losses were 60 % at highest in summer and 20 % at lowest in winter.

An energy efficient district heating system in Sonnenberg district of Ludwigsburg (Germany) was studied as a case system. Target of the project was to develop a simulation environment for studying integration of distributed renewable heat sources in existing and new systems. The focus was in demand side management of the system, building level heat supply and storage and substation level solutions enabling heat trade within the district heating system (two-way district heating). Partial results of this project will be implemented on a real heating network in the Sonnenberg district. A new low temperature (40/25 °C) extension to the existing (70/40 °C) district heating network has been established. The heat supply consists of a 350 kW gas CHP plant and a 200 kW geothermal heat pump. The project started in 1/2012 and ended in 3/2015.

The Wüstenrot (Germany) case study represents a plus energy community. It consists of 24 mostly single family houses, built almost according to local passive house standard. All buildings have large solar panel systems on the roof-tops and battery storages. The heat demand of the buildings is supplied by decentralised heat pumps and heat storages, which in turn are connected to a centralised geothermal system. This system consists of a cold water district heating network delivering low temperature water from a novel agro-thermal collector to the heat pumps within the buildings. The concept includes activation of agricultural fields as geothermal collectors by ploughing tubes in 2 m depth, the distance between the tubes being 0.5 to 1.0 m. The cold water network can be also used for direct cooling of the buildings in summer time. The system also offers a possibility to use the network as a heat sink for the heat pumps and can utilise heat sources like condensing heat of cooling systems and other sources for highly efficient use of energy. In the demonstration system this concept was demonstrated and analysed by integration of a cooling system in a nearby supermarket. Six to eight buildings were monitored as a first step, extended later to 10 to 15 buildings. Total duration of the monitoring activity was planned to be 3-4 years. Monitoring period started in 3/2014 with the main targets being the demonstration of efficiency, economic viability and system and building energy management as well as the operation of cold water network and agro-thermal collectors. The simulated heat demand for a single house was 20.35 MWh and electricity consumption 4.1 MWh. Measured heat demand for ten months was 27.2 MWh and electricity demand 5.4 MWh. The heat pump COP was 4.8 in average with variation between 2.5 to 6.5. The project ran from 11/2012 to 6/2016.

The case study "Zum Feldlager" in Kassel (Germany) is a low temperature district heating system supplying heat for 127 buildings by utilising solar collectors, a centralised ground heat pump with boreholes utilised also as seasonal heat storage. Heat storage is loaded by unglazed solar collectors (swimming pool absorbers as the low-cost option). The buildings are south-facing, specific heat demand being 45 kWh/m²·a and domestic hot water demand 730 kWh/person·a. Resulting total heat demand is less than 50 kWh/m²·a. The supply temperature in the district heating network is 40 °C. Connection for the space heating is implemented using heat exchangers, but for the preparation of domestic hot water there are different options; thermal solar collectors (e.g. flat-plate collectors) or an electric heating element complementing district heating. Aim is to find an optimal balance between the economy, use of electric heating, available solar output and distribution heat losses in the network. The project was started 11/2015 and ended 8/2017. In late 2016, the decision has been made not

to realize this project approach because of time constraints. Total investment is estimated to 3.7 Million EUR, including a 1.0 Million EUR for research.
A district heating system in Hyvinkää (Finland) building fair (2013) area was a case study for investigating low temperature district heating. The building fair area consists of 40 consumers within an area of 17 ha. In the implemented system, about half of them are connected to district heating system, the rest having a building specific heating system; e.g. combination of solar PV and collectors or a heat pump. Heat distribution system in the houses can be floor heating, radiators and ventilation based heating. Different options for connecting detached houses to the district heating system were analyzed. Houses with solar collectors and a district heating connection were studied as well. Results of simulations showed that the majority of the solar energy is used for the domestic hot water, covering about half of its annual heating needs. Solar energy available for space heating is negligible. Simulations of different district heating network configurations showed the impact of connection rate. For 100 % connection rate case and adequate network structure, the yearly relative heat losses were at a reasonable 10 % level. The low (47 %) connection rate case resulted in 20 % heat losses. Temperature variation and drop within the network especially outside heating season was observed as a peculiarity for a low heat demand district heating system. By-pass arrangements were used to stabilize the flow and temperatures at the cost of increased heat losses, but service pipes still experienced a significant temperature drop. Low temperature variation for distribution resulted in lower heat losses, but approximately doubled consumption of electricity in pumping.
The demonstration project in Sønderby (Denmark) was a full scale renovation of a part of an existing district heating system enabling a change from traditional distribution temperatures to a low temperature system. The area included 75 single family houses with the living area of 110 to 212 m² each, built in 1997-1998 with underfloor heating systems. The houses originally had hot water tanks for domestic hot water supply (110 l or 150 l in volume). The annual heat consumption of the buildings (based on heating seasons 2004/2005 - 2009/2010) was in range of 5 - 23 MWh/house. In the demonstration project, the old inefficient pipes within the network were replaced by better insulated pipes and the old water storage tank substations were replaced with heat exchanger substations. The low-temperature network in the area uses return pipeline in the medium-temperature network from the neighboring Taastrup district heating network as heat supply. Measurement data was processed and analyzed for a period between 1/2012 and 7/2013. The supply temperature averaged at 48 °C with heat from the return pipeline covering about 80 % of the total heat supply. The remaining heat was supplied by warmer water from the feed pipeline in the neighboring network. The results showed that it is possible to provide consumers a supply temperature of 50 - 53 °C, which is sufficient for space heating and domestic hot water supply. Heat losses in the old medium temperature system were approximately 41 % while in the new system reached heat losses of 13 – 14 %. The reduction was due to lower supply temperature and better insulation in pipelines. The average supply temperature was 55 °C and return temperature is around 40 °C, which results an overall cooling of about 15 °C. The reduced cooling resulted in greater need for pumping, but in costs this was comparably small in total savings due reduced heat losses. There are several explanations for the higher return temperatures, but the main reasons are too high bypass flow in some substations caused by defective or incorrectly set control valves. One advantage of the concept is the increased available capacity for the existing district heating system without any investment on production.
In Ulstein (Norway) fjord district heating is based on utilisation of the "free" heat from the sea by using decentralized heat pumps. A common heat exchanger is utilized to take the heat from the sea. The sea heat with low temperature is then distributed to energy substations. Both heating and cooling are distributed by using the same pipe network without insulation. The local energy substation could be used for one or few buildings. This solution with utilisation of sea

heat and decentralized heat pumps is suitable for places located at coast. The total heat supply delivered by the district heating system will be higher than 10 MW within five years. Including the reserve capacity, the plant should deliver about 20 GWh heating and 5 GWh cooling.

Middelfart (Denmark) district heating company has succeeded in lowering supply and return temperatures in their system from an average of 80.6/47.6 °C to 64.6 /40.0 °C during 2015. The district heating network in question is 139 km long in pipe length and services approximately 5000 customers. The heat supply consists of surplus heat from an oil refinery, a CHP plant and a waste incineration plant. The annual heat consumption is approximately 480,000 GJ. The district heating company has taken part in the development and testing of software tools that have helped in reducing the also return temperature in district heating network. Furthermore, the company has demonstrated a process that district heating companies can follow when aiming for a low-temperature distribution. During the process the network heat losses in Middelfart have been reduced by 25 % and the economic benefits were estimated to be approximately 5.5 million DKK (0.7 million EUR). The economic savings obtained from the temperature reduction consist of savings due to lower heat loss and savings from a return temperature tariff that is paid to the local heat supplier. The savings have been estimated to be in the size of 110,000 DKK/ year per °C (14,650 EUR/year per °C) due to heat loss reduction and 380,000 DKK/ year per °C (50,650 EUR/year per °C) due to the tariff to the heat supplier. The demonstration project has successfully shown how temperature optimisation can be implemented in existing district heating systems, and that it can lead to a significant energy efficiency improvement. The project demonstrates the possibility of including customer installations in the optimisation of the district heating system by monitoring the operation of customer substations, providing service checks for customer installations, and implementing a return temperature tariff that motivates consumers to improve their own internal heat distribution systems.

8 CONCLUSIONS

Low temperature district heating is a heat supply technology for efficient, environmental friendly and cost effective community supply. In comparison to conventional district heating, the network supply temperature is reduced down to approximately 50 °C or even less. To achieve maximum efficiencies, the energy conversion process, the district heating network and the end user installation within the supplied buildings need to be optimized to utilize lower network supply temperatures. Therefore, the focus of the DHC Annex TS1 is on low temperature district heating for the application in space heating and domestic hot water preparation. The main objective of the DHC Annex TS1 is to demonstrate and validate the potential of low temperature district heating as one of the most cost efficient technology solution for heating energy supply to achieve 100 % renewable and GHG emission-free energy systems on a community level. This objective is obtained by the development and collection of assessment tools as well as providing guidelines, recommendations, best-practice examples and background material for designers and decision makers in the fields of building, energy production/supply and politics.

The benefits of low temperature district heating are both in heat distribution and heat generation. In the heat distribution, the heat losses, the thermal stress and the risk of scalding are reduced and the quality match between heat supply and heat demand is improved. In the heat generation, lower supply and return temperature helps to improve the power to heat ratio in combined heat and power plant and recover waste heat through flue gas condensation. Low supply temperatures help to achieve higher efficiencies for heat pumps, and enlarge the utilization of low-temperature waste heat and renewable energy. Low temperature district heating has been continuously developed and is ready to replace the currently used district heating systems.

Low temperature district heating based on renewable energy can substantially reduce total greenhouse gas emissions and secure energy supply for future development of society. It has the ability to supply low temperature district heating for space heating and domestic hot water for various types of buildings, to distribute heat with low heat losses and ability to recycle heat from low temperature waste heat and renewable energy sources. From various research and development of low temperature district heating projects, it has been shown that it is both technically feasible and economically sound to change current high/medium temperature district heating system to low temperature district heating for both new and existing building areas.

As part of the IEA DHC Annex TS1 project promising technologies and ideas for low temperature district heating application have been collected and identified to meet the goals of future renewable based community energy systems. Innovative technologies and advanced system concepts in low temperature district heating are reported for heat generation, distribution and end user utilization. In a special technology chapter (chapter 4) background materials and cutting edge knowledge on district heating pipe systems, network designs, hygienic domestic hot water preparation in low temperature supply schemes, space heating controls and the integration of small scale decentralized heat sources is provided for designers as well as decision makers in the building and district energy sector.

To meet the goals of future renewable based community energy systems improved interfaces in district heating need to be established and may be explained via hard and soft issues in chapter 5. Here, energy planning of the future integrated energy systems is identified as a complex problem. The analysis of the future heat demand showed that the district heating would still be needed for most of the buildings in 2050, inducing that the low temperature district heating would be a promising heat supply for the future and for many buildings. Considering that there is enough available heat from renewables and waste heat sources at the low temperature level, the low temperature district heating will be of high relevance in the future. For future development of the district heating and a high reliability of the low temperature district heating, stati-

stical data and knowledge on the heat losses and how operation and temperature levels may contribute to the distribution losses are highly necessary. For example, only companies that have a long-term plan to include renewable energy sources have good databases and documentation on heat losses and temperature levels.
The integration of distributed energy systems will be realized by a new actor at the district heating market called "prosumer". A prosumer is a customer that both produces and consumes heat from the district heating system. An increasing number of the prosumers will require a transformation of today's district heating network into smart grid. New and intelligent control strategies for the management of the different temperature levels and differential pressures in the network are of greatest importance to enable the successful connection of the prosumers into the district heating system. Therefore, intelligent data management may create new business models for both the district heating companies and the information technology sector.
For the identification of integral and innovative approaches to low temperature heat supply at municipal level, an overview of existing evaluation methods is provided in chapter 6. Initially, a classification form for local and district heating models was developed and distributed to tool developers. After obtaining the completed classification forms from the Annex participants, the planning tools were assessed in seven categories: analytical approach (energy system model, thermodynamic model, other), target group of users (municipal authorities, professional planners, R&D), level of detail (geographical scope, time horizon), model type (simulation, optimization), demand categories (households, commercial, industry, transportation), final energy consumption (electricity, heat, transport) and used variables (costs, energy, exergy, temperature).
The evaluation has shown some promising approaches for low temperature district heating. However, there was none found to be fully appropriate for the objective of a simplified, holistic tool for low temperature district heating. By evaluating the selected planning tools for district heating schemes, requirements can be derived for the development of a simplified planning tool.
The Easy District Analysis (EDA) tool was developed, based on the identified requirements for a simplified district heating planning tool. The intended target groups of the tool are urban planners and planners in utility companies. The tool is intended to be used in the pre-planning phase of a district energy system. The focus of the tool is on the evaluation of the impact of different grid temperatures (e.g. standard district heating vs. low temperature district heating) and of different operation modes (technical vs. economic operation) of district heating technologies. The assessment is based on the parameters primary energy consumption, carbon emissions and heat production costs.
The practical application of the tool is shown in the assessment of a case study with an existing housing stock. Based on the identification of the initial heating systems and building standards as well as the costs for a change of energy carriers, suitable areas for a possible realization of low temperature district heating schemes can be determined. This assessment includes technical and socio-economic criteria from different groups of actors and actor-specific measures could be identified to support the implementation of low temperature district heating.
Core objective for the description of case studies in chapter 7 was to identify and to collect innovative demonstration concepts as examples of success stories for communities interested in developing low temperature district heating systems. Demonstrated cases include the use of advanced technologies and the interaction between different components within the systems. Based on these experiences, principles and lessons learned in designing these systems are given. Measurement data from community projects are also used in validation of the models and tools developed.
There were a total of eight case studies from Germany, Denmark, Finland, Norway and Great Britain. The district heating systems were of very different sizes, from smaller building groups to city wide systems. Taking into account the size of the supply area, the network lengths vary from 165 m to 140,000 m. The connected buildings were residential buildings of different sizes, and mostly low energy or passi-

ve houses. Sources of heat were solar collectors, heat pumps, CHP plants, excess heat from industry or the systems were connected to a larger network close by with heat exchangers. The temperature levels recorded were typical for low-temperature systems, varying from 40 to 60 °C in supply and 25 to 40 °C in return. Savings and increased efficiencies were observed in every case studied. The material collected and summarized in this guidebook show that low temperature district heating is a key enabling technology to increase the integration of renewable and waste energy for heating and cooling.

Low temperature district heating is one of the most cost efficient technology solutions to achieve 100 % renewable and GHG emission-free energy systems on a community level.

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LIST OF ABBREVIATIONS

4GDH	4th Generation District Heating
BHE	Borehole Heat Exchanger
CB	Comfortable Bathroom Concept
CHP	Combined Heat and Power
COP	Coefficient of Performance
CSH	Code for Sustainable Home in UK
DH	District Heating
DHC	District Heating and Cooling
DHSU	District Heating Storage Unit
DHW	Domestic Hot Water
DWC	Domestic Water Cold
DWH	Domestic Water Hot
EDA	Easy District Analysis – Tool
GHG	Green House Gas
IEA	International Energy Agency
IHEU	Instantaneous Heat Exchanger Unit
LCA	Life Cycle Assessment
LCC	Life Cycle Cost Analysis
LTDH	Low Temperature District Heating
MFH	Multi-Family House
OECD	Organization for Economic Cooperation and Development
PV	Photovoltaic
RES	Renewable Energy Source
RTO	Return Temperature Optimization
SDH	Semi-Detached House
SFH	Single Family House
SH	Space Heating
TCP	Technology Collaboration Platform
TH	Terraced House
TRV	Thermostatic Radiator Valve

APPENDIX A: NATIONAL STANDARDS AND GUIDELINES ON DOMESTIC HOT WATER OF IEA DHC PARTICIPATING COUNTRIES

One of the main issues and challenges of low temperature district heating supply regarding hygienic aspects of domestic hot water DHW supply are temperature levels below 60 °C and sizes of the system of more than 3 litres (Brand 2013, Yang 2016 and Bartram et al. 2007). The required temperature levels for safe and hygienically unexceptionable DHW supply vary from to country. Against this background an analysis of regulations and guidelines of the member countries participating in the project "IEA DHC Annex TS1" in the program “District Heating and Cooling” (DHC) of the International Energy Agency are analyzed and documented. An overview of the regulations and guidelines is given below.

Member Country	Description	Standardisation
Denmark	The national regulation DS 439 (DS 439 2009) states that the DHW system should be designed to be capable of preparing DHW at 60 °C and maintain at least 50 °C in all the distribution lines. During peak load a minimum temperature level of 45 °C is sufficient. In contrast to EN 806 (EN 806-1:2000 and EN 806-2:2005) there is no differentiation in small and large systems. In traditional DHW systems, mostly due to large system volume of e.g. storages, it has to be ensured that the return temperature from the DHW recirculation is 50 °C in order to prevent the risk of Legionella. As a consequence, the current DH minimum supply temperature is above 60 °C.	DS439:2009 Code of practice for domestic hot water supply installation
Finland	The temperature level in the entire DHW system has to be at least at 55 ° C. In case of peak load, this temperature may drop for maximal ten seconds. Due to the risk of scalding the maximum permitted temperature level of DHW is 65 °C. In case of DH supply it is recommended that substations have to be designed so that the DHW from the heat exchangers (HE) is higher than 58 °C. In case of DHW commonly instantaneous HEs are used. As a result the current DH minimum supply temperature is above 60 °C.	National Building Code of Finland D1: Water supply and sewerage equipment of properties, regulations and guidelines (YM 2007)
Germany	The regulation is valid for all new systems with a storage size > 400 litres and a hydraulic loops > 3 litres, if they are not installed in a single- or two-family houses. There should be at least 60 °C at the water outlet of the boiler. The temperature difference inside the pipe network is supposed to amount 5 °C maximum, circulation included. Pipes over several floors with a water volume > 3 litres should be equipped with an additional circulation pipe or self-regulating trace heating. The circulation or electrical trace heating must not be interrupted for longer than 8 hours per day. In case of DHW preparation using DH a hot water temperature of more than 60 °C has to be maintained in order to avoid contamination of the hot water system with legionella.	DVGW-Arbeitsblatt W551 - Technische Maßnahmen zur Minderung des Legionellenwachstums in Neuanlagen (DVGW W551 2004)

Member Country	Description	Standardisation
Great Britain	The temperature level of the DHW systems including the storage may not drop below 60 °C. At the tapping point a temperature level 50 °C of DHW should be reached within one minute, in buildings with high hygienic standards at 55 °C. Significant higher temperatures should be avoided because of the risk of scalding. In case of a DHW supply using instantaneous heat exchangers, the required temperatures and time specifications do not have to be fulfilled. In case of using instantaneous heat exchangers it has to be ensured, that installation is directly connected to the DHW supply. The volume between pipe and heat exchanger should be less than one litre and the volume between heat exchanger and tapping point should less than 1.5 litres. The maximum permissible temperature level of DCW is 20 °C.	HSG274 Legionnaires' disease: Technical guidance Part 2 (HSE 2014)
Korea	The required temperatures varies depending on the case of application: Inlet temperature (heat generator) Central heating 120-180 °C (ΔT: 40 K) District/local heating supply Seoul Housing & Communities Corporation: 115-60 °C (ΔT: 55 K) Korea District heating Corporation: SH 115-50 °C (ΔT: 65 K) Required temperature level of the DHW inside the storage Central heating 60-50 °C (ΔT: 10 K) Local heating 60-50 °C (ΔT: 10 K) District/local heating supply Seoul Housing & Communities Corporation: 60-45 °C (ΔT: 15 K) Korea District heating Corporation: SH 60-45 °C (ΔT: 15 K)	Technical Guidelines (Seoul Housing & Communities Corporation) (ISH 2017)
Norway	The DHW system must be designed so that the temperature at any tap point in the system reaches at least 60 °C within one minute after opening a tap. The return temperature in DHW systems with continuous water circulation must not be less than 60 °C. Due to hygienic reasons the whole DHW system must be flushed regularly with water at a temperature of at least 70 °C. The temperature in DHW storages must be at least 70 °C. The same conditions must be fulfilled for DHW connected to district heating systems.	Prevention of Legionella – guidelines, 3. edition, chapter 7. National Institute of Public Health (Pettersen 2015)
Sweden	Installations for domestic hot water should be designed so that a water temperature of less than 50 °C can be achieved after the tap. To reduce the risk of scalding, the temperature of the hot tap water is limited to 60 °C after the tap. If there is a special risk of accidents the temperature of the hot tap water has to lower than 38 °C. Devices for control of DHW should be designed so that the risk of injury from the confusion of domestic hot and cold tap water is limited. The heat-up of the DCW system must be avoided.	6: BFS 2015:3 BBR 22 - Section 621 (BFS 2011:6)

Next to the detailed analysis of the regulations and guidelines of the IEA DHC Annex TS1 member countries, the regulations of further DHC member countries are reviewed. In Canada, electrical heat generators have a factory default settings of 60 °C. In the US the requirement of warm water is at about 5,000 kWh per apartment and year which is nearly twice as the demand in Germany. This is mainly due to the reason that dishwasher and other sectors in industry and households are directly supplied with warm water. The operating temperature of condensing boilers is at 48 °C which is also suggested by the government (Dalla Rosa et al. 2014). The general recommendation of the "ASHRAE Guideline 12-2000" (ASHRAE 2000) also used in Canada and the USA is a system temperature of 55 °C. In the Netherlands, the "Modelbeheersplan legionellapreventie in Leidingwater" obliges that the temperature of drinking warm water systems must not drop below 60 °C (VROM 2000). In

France, the temperature at the tapping point for personal hygiene should not exceed 50 °C, as it is regulated in "Arrête du 30 novembre 2005 modifiant l'arrêté du 23 juin 1978 - Installations for the distribution of domestic hot Water" (JORF 2005). At other tapping points, temperatures up to 60 °C are allowed. In addition to that, it is distinguished in small and large plants analogically to the German regulation. For large-scaled plants, there are further specifications: the temperature at the generator outlet must not drop below 55 °C and there has to be a periodical thermal flush. In the Switzerland the national norm SIA 385 (SIA 385 2011) states that the outlet temperature of the water heaters should be 60 °C, the temperature level of warm kept pipes (circulation and warm keeping system till access into the water heater) is 55 °C and at the tapping point at least 50 °C. Systems with temperatures lower than 60 °C, e.g. fresh water stations, are possible, but they have to be heated up to 60 °C for one hour once a day (disinfection) (SIA 385 2011).

The analysis of the different regulations shows that regulations of the different countries are dealing mostly with traditional DWI with mostly high volumes for drinking water supply. The technical methods for the supply of drinking water, described as part of the regulations and guidelines, consider especially hygienic aspects due to a minimisation of health risks. Alternative and energy efficient methods are not or only insufficiently regarded.

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APPENDIX C: ADDITIONAL INFORMATION FROM IEA DHC ANNEX TS1

All additional information is available via the homepage of IEA DHC:
www.iea-dhc.org

Flyer

The flyer gives an overview of the activities of the DHC Annex TS1 working group and a short introduction into the benefits and challenges of low temperature district heating schemes.

DHC Annex TS1 Guidebook

A printable .pdf version of the "Future Low Temperature District Heating Design Guidebook", the final report of this project, is available for those who prefer to get a good and consistent overview about the perspectives of low temperature district heating and its application.

Case Study Brochure

The brochure "Successful Implementation of Innovative Energy Systems in Communities – with Low Temperature District Heating and Renewable Energy Sources" gives an overview of the identified case studies with short descriptions of the implemented technologies and the boundary conditions as well as local conditions.

Tool

The EDA tool (Easy District Analysis) is an excel-based simulation tool that has been developed by the IER (Institute of Energy Economics and Rational Use of Energy) at the University of Stuttgart (Germany) in cooperation with Annex TS 1 participants. It enables the easy analysis of districts in terms of energy consumption, CO_2 emissions and costs of different DH supply options. More information is available directly from the Annex participants from IER Stuttgart.

Detailed Subtask Reports

From two subtasks (compare Figure 1-1 on pageSeite 10) special and more detailed reports have been published. These are:

- Subtask report A: Methods and Planning Tools
- Subtask report D: Case studies and demonstrations

The reports are freely available and can be found on the named homepage.

Material from Workshops:

A number of workshops have been organized by the Annex TS1 participants to enhance the exchange with other experts. The proceedings from these workshops are available from the indicated homepage:

- Industry and R&D workshop on
  "Energy Efficiency and Hygiene in Drinking Water Installations"
  Norwegian University of Science and Technology, Trondheim, Norway
  May 20, 2015

- Industry and R&D workshop on
  "Transition of Existing District Heating Grids to Low Temperature Grids"
  Danfoss A/S Headquarters, Nordborg, Denmark
  September 23, 2015

- Industry and R&D workshop on
  “Realization of Innovative Low Temperature District Heating Systems in Communities”
  Frankfurt Fair and German Heat & Power Association, Frankfurt, Germany
  April 21, 2016

Conference Sessions:
Two special sessions on the topics of Annex TS1 have been arranged by the working group. More detailed material of the sessions is available from the Operating Agent:

- Technical Session of Annex TS1 on
  “Fossil Free Building Stock Realized Based on Low Temperature District Heating!”
  at CLIMA 12th REHVA World Congress, Aalborg, Denmark
  May 24, 2016

- Special Session of Annex TS1 on
  “Low Temperature District Heating for Future Energy Systems”
  at 15th International Symposium on DHC 2016, Seoul, Korea
  September 06, 2016

Published articles
A large number of conference articles and journal papers have been published by the Annex TS1 participants. A list of references is available via the homepage.

Technical presentations
A series of technical presentations were prepared for the biannual IEA DHC Executive Committee (ExCo) meetings during the working time of Annex TS1 and are available from the Operating Agent.

THE LOW TEMPERATURE DISTRICT HEATING RESEARCH PROGRAM

The IEA DHC Annex TS1 aims to identify holistic and innovative approaches to communal low temperature heat supply by using district heating. It is a framework that promotes the discussion of future but also existing heating networks with an international group of experts.

The goal is to obtain a common development direction for the wide application of low temperature district heating systems in the near future. District cooling can also be integrated into the activities but is not the focus. The gathered research which is going to be collected within this Annex should contribute to establishing DH as a significant factor for the development of 100 % renewable energy based communal energy systems in practice.

By connecting the demand side (community/building stock) and the generation side (different energy sources which are suitable to be fed in the DH grids), this technology provides benefits and challenges at various levels.

The activities are strongly targeted at DH technologies and the economic boundary conditions of this field of technology.

MORE INFORMATION ABOUT THE PROGRAM:

Up to date information about the participants and the progress of the research program is available on the web page:

www.iea-dhc.org

IEA DHC|CHP

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